DIRECTIONS TO THE BINDER.

PROCEEDINGS—1852.

The previous Title pages, January to October inclusive, to be cancelled.

The present Title page, List of Council, and Index, to be inserted at the commencement, and the Plates Nos. 48 to 83, inclusive, to be all placed together at the end of the volume.

INSTITUTION

OF

MECHANICAL ENGINEERS.

PROCEEDINGS.

1852.

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INDEX.

1852.

COUNCIL, 1852.

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JAMES E. MCCONNELL, . .	Wolverton.
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Institution of Mechanical Engineers,

81 *Newhall Street, Birmingham.*

PROCEEDINGS.

JANUARY 28, 1852.

THE FIFTH ANNUAL GENERAL MEETING of the Members was held at the House of the Institution, Newhall Street, Birmingham, on Wednesday, 28th January, 1852, J. E. McCONNELL, Esq., Vice-President, in the Chair.

The minutes of the last General Meeting were read by the Secretary and confirmed.

The CHAIRMAN then read the following

REPORT OF THE COUNCIL,

AT THE FIFTH ANNUAL MEETING OF THE INSTITUTION OF MECHANICAL ENGINEERS.

The Council have the pleasure of meeting the Members on this Fifth Anniversary of the establishment of the Institution, and of congratulating them on its continued prosperity and increasing efficiency in promoting the objects for which it was founded.

The number of Members, &c., for the last year is 203, of whom 15 are Honorary Members, and 4 Graduates.

The Financial statement of the affairs of the Institution for the year ending 31st December, 1851, shows a Balance in the Treasurer's hands of £202 15s. 2d., after the payment of all accounts due to that date. The Finance Committee have examined and checked all the receipts and payments of the Institution for the last year, 1851, and have reported that the following Balance Sheet, rendered by the Treasurer, is correct.

(*See Balance Sheet appended.*)

The Council have the pleasure of announcing that the following donations to the library of the Institution have been received during the past year:—

D. K. Clark, on Railway Machinery, from the Author.

W. Fairbairn, Lectures on the Construction of Boilers and on Boiler Explosions, from the Author.

H. Lund on the Law of Patents, from the Author.

J. Weale, Dictionary of Terms in Engineering, &c., from the Editor.

Minutes of Proceedings of the Institution of Civil Engineers.

The Mechanic's Magazine, from the Editor.

The Practical Mechanic's Journal, from the Editor.

The Civil Engineer and Architect's Journal, from the Editor.

The Artizan, from the Editor.

The Mining Journal, from the Editor.

The London Journal of Arts, from the Editor.

The Patent Journal, from the Editor.

Bust of Thomas Telford, by Mr. Peter Hollins.

Portraits of Messrs. George Stephenson, Robert Stephenson, Joseph Locke, and George P. Bidder, from Mr. Henry Wright.

The Council cannot but record their sense of the value and interest of the papers that have been presented to the Institution during the last year, and their thanks to the authors of the papers for the useful practical information they have furnished to the Institution. They have good prospect of continued advancement in the importance and number of the communications brought before the Institution, and have promises of several valuable papers for the ensuing year.

The following papers have been read at the Meetings in the last year:—

The Improvement of the Construction of Railway Carrying Stock, by W. A. Adams, Birmingham.

An Improved Water Meter, by W. Parkinson, London.

The Locomotive Workshops of the Manchester, Sheffield, and Lincolnshire Railway, by R. Peacock, Manchester.

An Improved Vacuum Gauge for Condensing Engines, by F. J. Bramwell, London.

An Improved Axle Box for Railway Engines and Carriages, by J. Barrans, London.

The Ventilation of Coal Mines, by Benjamin Gibbons, Dudley,

A New Machine for Blooming Iron, by Joseph Beasley, Smethwick.

The Improvements in Locks in the United States of America, by P. R. Hodge, London.

Improvements in the Construction of Railway Waggons, by H. H. Henson, London.

A New Regenerative Condenser for High Pressure and Low Pressure Steam Engines, by C. W. Siemens, Birmingham.

A New Blowing Engine Working at High Velocities, by Archibald Slate, Dudley.

An Improved Mode of Moulding Railway Chairs, by E. A. Cowper, Birmingham.

A New Pendulous Reciprocating Steam Engine, by J. A. Shipton, Manchester.

The Preservation of Timber by Creosote, by J. E. Clift, Birmingham.

A New Equilibrium Canal Lift, by A. Slate, Dudley.

An Improved Miner's Safety Lamp, by S. H. Blackwell, Dudley.

The Council are desirous to urge particularly on the Members the preparation of papers on some engineering subjects that have come under their attention, either as improvements in construction, or the results of experience and practical working; and they would especially call attention to the investigation of the following important subjects:—

The Explosions of Steam Boilers.

The Relative Economy of Stationary Engines for Manufacturing and Mining Purposes.

The Best Construction of Marine Engine Boilers.

The Comparison of Paddle-wheels and Screw Propellers.

The Construction of Iron Steam Vessels.

The Prevention of Explosions in Mines.

Improvements in the Construction of Railway Carrying Stock.

Improvements in Corn Mills.

Improvements in Self-Acting Tools, and Workshop Economics.

A further list of proposed subjects for papers is appended; and the Council hope that all the Members will endeavour to prepare communications on some professional subjects that will be serviceable and interesting to the Institution, for the mutual advantage and information of the Members, as well as the general advancement of the interests of manufactures and commerce. They also invite the Members to aid as much as possible in increasing the utility of the Institution by the formation of a collection of mechanical models and drawings, and books for the library, with indicator-cards from steam engines, and statistical returns of the working of engines, &c., so as to render the Institution a complete place for reference on mechanical subjects.

The Council refer with satisfaction to the Meeting of the Institution that was held in London in the last year, during the Great Exhibition of Industry, at which a number of distinguished foreign engineers and scientific men were present, including Foreign Jurors of the Exhibition, and they were afterwards entertained at a dinner given by the Members of the Institution, in celebration of the occasion, at which 170 of the members and their friends were present, forming an interesting and agreeable assembly.

The Officers of the Institution, and Five of the Members of the Council in rotation, go out of office this day, according

to the Rules, and the ballot will be taken at the present Annual Meeting for the election of the Officers and Council for the ensuing year.

The CHAIRMAN observed, that, on the present occasion of their fifth anniversary, they could look back with great satisfaction to the progress of the Institution, and the warmest expectations of its originators had certainly not been disappointed. Many valuable papers had been brought out by the Institution of mutual advantage to the members, and often productive of useful suggestions to the authors of the papers from the discussions that took place at the meetings. He trusted that what had been begun so well, would be carried on in the same spirit, for the Institution might be considered as still only in its infancy ; and it was the duty of all the members to assist and support the Institution, by furnishing all the information in their power. Such a means of developing mechanical knowledge and manufacturing energy, as this Institution afforded, would prove a commercial advantage to the country generally, and they could only succeed in keeping their national position in machinery and manufactures, by uniting together in the encouragement of such Institutions. The prominent position of this country in the markets of the world, was maintained principally by the development of those mechanical resources which economise labour ; and last year's Exhibition showed them pretty plainly, that to maintain that position they must energetically follow out the course of improvement which had first given England her supremacy. The Chairman hoped their numbers would be increased by younger members, in the class of graduates, who would be of good service to the Institution, to rise up in time and succeed to the places of the older Members. Every practical man had daily passing under his notice much of valuable information, which would be serviceable to the Institution, and he hoped that every Member would communicate such practical information, and avail himself of the

assistance of the Secretary for the purpose, who would afford every facility in preparing it; as it often occurred that those who had the most information to communicate had the least time to spare for it, or they were not aware that the information would be serviceable to the Institution.

Mr. THORNTON moved the adoption of the Report, and observed that he considered the progress and the present position of the Institution was very satisfactory.

Mr. HENSON seconded the motion, which was passed.

Mr. SHANKS moved a vote of thanks to the Council of the Institution, for their services during the past year, which was seconded by Mr. GARLAND, and passed.

The CHAIRMAN then announced that the ballot papers had been opened by the Committee appointed for the purpose, and the following Officers and Members of Council were elected for the ensuing year. He observed that the Committee had reported that a number of the ballot papers sent in by the Members had to be rejected as informal, because the Members had sent the papers blank, without indicating the names that they voted for.

President:

ROBERT STEPHENSON, M.P., London.

Vice-Presidents:

CHARLES BEYER, Manchester.
J. E. MCCONNELL, Wolverton.
JOHN PENN, London.

Council:

MATTHEW KIRTLEY, Derby.
JOHN R. MCCLEAN, London.
R. B. PRESTON, Liverpool.
JOHN RAMSBOTTOM, Manchester.
THOMAS WALKER, Wednesbury.

(In addition to the Ten Members of Council who continue in office from the last year.)

Treasurer:

Charles Geach, M.P., Birmingham.

Secretary:

William P. Marshall, Birmingham.

The Chairman announced that the following new Members were also elected:—

Members:

Alexander Brogden, Walsall.
Henry Brogden, Walsall.
Thomas Fairbairn, Manchester.
James Fenton, Low Moor.
James Holcroft, Shut End.
Reuben Plant, Brierley Hill.

The following paper, by Mr. Andrew Lamb, of Southampton, was then read:—

ON AN IMPROVED BOILER FOR MARINE ENGINES.

The Peninsular and Oriental steam ship "Ripon" is an iron vessel, of 1650 tons burthen, and has two oscillating engines, of 450 nominal horse-power. She was built by Messrs. Wigram, in 1846, and was supplied with her machinery by Miller, Ravenhill, and Co., of London, since which time she has been almost constantly running for the conveyance of the Indian Mail from Southampton to Alexandria.

Her average speed for the whole of this time has been 9·1 knots per hour. The boilers fitted to her by Messrs. Miller were of the ordinary tubular construction. They were in six pieces, had twelve furnaces, and 744 iron tubes, 3¼ inches outside diameter, 6 feet 6

inches long. The total fire-bar surface was 212 square feet, and the heating surface in tubes 3798 square feet, reckoning the whole of the inside surface of the tubes as effective.

The sectional area through tubes equals 36½ square feet; ditto through ferules, 28 square feet. These boilers were loaded to 10 lbs. on the square inch, but in consequence of being deficient in steam, the actual pressure attained at sea very seldom exceeded 4 to 6 lbs. when full steam was admitted to the cylinders;—of course the engineers found it to their advantage to keep it up to its full pressure by working the expansion apparatus. This deficiency of steam was found to be an increasing evil, the cause for which may be satisfactorily explained by a little consideration of the *modus operandi* of the sea-going Tubular Boiler. When commencing running with the boilers new, for a short period, dependent on the species of coal consumed, the Tubular Boiler offers its greatest advantage, and is in fact (when properly constructed) as good an apparatus for evaporating water as can be imagined applicable to marine purposes. The tubes give an immense amount of heating surface, and in small compass, and from their form are capable of resisting great pressure, but after three or four days' steaming these advantages diminish. The tubes have an accumulation of soot and light ashes inside them, which by reducing their sectional area, sometimes from 50 to 75 per cent., diminishes the draught through the furnaces in the same proportion, and also reduces the effective heating surface to the same serious extent. This accumulation depends in quantity very much upon the coal. On one occasion the author was present in a vessel with Tubular Boilers, burning Scotch coal, and they actually came to a dead stand, after only sixty hours' steaming, the tubes being nearly choked up, and requiring to be swept. When Tubular Boilers have made a few voyages at sea, the outside of the tubes becomes encrusted with saline matter, which gradually accumulates upon them, chiefly upon their bottom sides, and which hitherto it has been found impossible to remove by any other means than scaling them mechanically. The situation of the tubes (row over row) prevents this being accomplished, excepting upon the upper tiers, and the consequences are that the tubes become coated with a crust ¼ or ⅜ths of an inch thick, and the tube-plates also, which

from its non-conducting nature greatly retards the transmission of the heat through it, and the tube-plates becoming hot, crack and blister, and deteriorate very rapidly.

For the Boiler to be described in the present paper, invented and patented by the author in conjunction with Mr. Summers, the following advantages are claimed over its Tubular competitor :—

1st.—That, while it possesses an equal amount of heating surface in the same space as Tubular Boilers, it is free from the evil of choking with inside deposits of soot and ashes, because the flues being in one sheet for their whole depth, the deposit falls into the bottom of the flues, and is swept by the draught through into the uptake, and thence into the chimney.

This Improved Boiler, as adopted in the "Ripon," is shown in the accompanying drawings, Figs. 1, 2, and 3, Plates 48 and 49.

Fig. 1 is a transverse section, Fig. 2 a longitudinal section, and Fig. 3 a plan, all taken through the flues. AA are the Improved Flues, which are fixed in the same position as the tubes in an ordinary Tubular Boiler, forming the return passage from the back of the fire-grate at C to the uptake at D. EE are the smoke-box doors, and F the fire doors. The flues AA are flat rectangular chambers, 6 feet 9 inches long, and 3 feet 3 inches high, open at each end where they are fixed to the boiler. There are seven of these flues to each fire-grate; the smoke spaces are $1\frac{3}{4}$ inches wide, and the water spaces $2\frac{5}{8}$ inches. The sides of the flues are $\frac{1}{4}$ inch thick, and they are supported by the stays BB, fixed inside the flues. From this circumstance of there being no stays or other projections in the water spaces, an important advantage is gained—that no nucleus is offered round which the scale can collect, and no impediment to interfere with the complete and rapid cleansing of the water spaces from scale by means of the ordinary scrapers.

In another arrangement of these Boilers, adapted for large screw steamers, and also for war steamers, the flues are placed alongside the furnaces and at the same level, instead of over the furnaces as in the engravings, which arrangement protects the boilers from shot, by keeping them below the water line.

In these Improved Boilers the same amount of heating surface

can be obtained in the same capacity of boiler as with tubes; the only difference is, that if the tubes are $\frac{3}{16}$ths of an inch thick they will of course be rather lighter than $\frac{1}{4}$-inch plates; but this difference as compared with the gross weight is so small as to be unimportant. In the event of any accident to any of the flues, they may be taken out, separately or collectively, to be repaired or replaced with new ones; but from the facility with which they can be kept clean, they ought, as in the old-fashioned flue boilers, to wear out the shell; the length of time being remarkable that a *thin* plate will last, if kept clean, and never overheated.

The last boilers of this construction examined by the author were those of the "Tagus," 280 horse-power, and in those boilers, after six days steaming, the deposit was only three inches deep in the bottom of each flue; and the total depth of the flues being 3 feet 8 inches, it follows that she had only thus lost about 6 per cent. of sectional area.

2nd.—That the Improved Flues, from having no projection either of rivet heads or stays in the water spaces, offer no obstructions whatever to the scaling tool, and are as easily kept clean as any part of any boiler can possibly be, thereby entirely removing the evil of a loss of heat through non-conducting deposits, and very much increasing the durability of the Boiler.

3rd.—That the water spaces between the flues being comparatively large, and the sides of the flues perfectly vertical, the circulation of water in the boiler must necessarily be much more perfect than amongst a number of tubes (amounting sometimes to thousands), where the water has to wend its way in and out in curved lines. This greater perfection of circulation, the author thinks, must add greatly to the effectiveness of the heating surface in the Improved Flues.

It must be here mentioned that these advantages do not now rest upon theory only, and that they have been fully realized by experience.

The first boilers fitted with these flues were those in the "Pacha," in October, 1849, similar to those shown in the engravings, and up to the time of her unfortunate loss these boilers gave entire satisfaction. Then followed a small boat, in January, 1850, and the

"Tagus," in August, 1850, since which their success has been rapid, as a proof of which, numerous vessels of different companies are being and have been fitted with them. The "Tagus" has now the oldest of the boilers, and there is in no part of them any signs of deterioration whatever; in fact they are in every way perfect. There has never been any leakage, and the consumption of fuel is less than with her former Tubular Boilers.

The Improved Boilers now fitted to the "Ripon," were manufactured by Messrs. Summers, Day, and Baldock, of Southampton, and are in four parts; the boilers being placed in the wings, two forward of the Engines, and two aft, the stokeholes are thus in midships.

The space occupied by these new boilers is the same as the old ones, the arrangement mentioned having economised as much room as the increase size of boilers required, so that the same quantity of coal is carried in the same space as before. The new boilers have 16 furnaces and 246 square feet of fire-bar surface: 112 flues, 3 feet 9 inches deep × 6 feet 3 inches long, being 5440 square feet of heating surface, reckoning the whole inside surface (as in tubes); the sectional area through the flues, deducting the stays = 54 square feet.

This large sectional area can be diminished at pleasure by a grating damper, which is hung at the front end of the flues, and extends about 10 or 12 inches down them, and which is worked by handles placed outside the boiler and between the hinges of the smoke-box doors. The Engineer can thus regulate the intensity of his draught at pleasure, according to the variety of coal in use, &c., &c.

The new boilers of the "Ripon" are loaded to 13 lbs. per square inch; the flues, being strongly stayed inside, would of course resist a far higher pressure with perfect safety; in fact, if required, they might easily be sufficiently stayed to resist steam of any pressure.

The "Ripon," at the same time that the boilers were altered, had her common radial paddle-wheels replaced by feathering ones, which consequently added much to the speed of the vessel.

The best speed of the engines of the "Ripon" with the old arrangement was about 15 revolutions per minute, and that of the vessel about 10 knots per hour when quite light.

On the trial at the measured mile, December, 1851, the vessel was drawing 16 feet 3 inches forward, and 16 feet 7 inches aft; she had all her coal, (422 tons,) on board, her water, and some cargo, and consequently was pretty deep loaded. The speed of the engines was 19½ revolutions per minute, and of the vessel 11·3 knots per hour. Had she been light, as in the former trial, she would have probably gone over 12 knots. It appears, therefore, that the improvement in speed may be fairly stated as 2 knots per hour. The cylinders of the engines are 76 inches diameter × 7 feet stroke. Their nominal horse-power formerly, at 15 revolutions, would be 404, and at 19½ revolutions, 526 horse-power, so that the new boilers have given 122 horse-power more steam, of an increased pressure of 3 lbs. per square inch, than the old ones. As the "Ripon" is now making her first voyage with the new boilers, the author cannot speak with any certainty about her consumption, but will give some details of the Peninsular and Oriental steam ship "Bentinck," which has made one voyage to Alexandria and back with these improved boilers and feathering wheels.

The "Bentinck" is a wooden vessel, built by Wilson, of Liverpool, in 1844; and has side lever Engines, by Fawcett and Preston. She is 2020 tons burthen, and her Engines are 520 nominal horse-power; her original boilers were of the old flue construction, and were loaded to 6 lbs. per inch pressure; her average speed at sea was 9 knots per hour, and her Engines about 14 revolutions per minute.

The speed of the "Bentinck" is now over 11 knots per hour. The former consumption was about 37 cwt. per hour; the present consumption averages about 38 cwt. per hour.

It must be noticed that the Peninsular and Oriental Company had Tubular Boilers, with brass tubes, made for this vessel by Messrs. Bury, Curtis, and Kennedy, and that they were brought to Southampton, and placed in the "Pottinger," a sister ship of the "Ripon," and of 450 nominal horse-power, with common paddle-wheels: these boilers are of exactly the same size as the patent boilers made for the "Bentinck," and they are both loaded to the same pressure, viz., 12 lbs. per square inch; they have each made a passage to Alexandria and back, and, contrary to all expectation,

the "Bentinck," although her Engines are 70 horse-power nominal more than the "Pottinger," and are working up to 103 horse-power more, has consumed 128 tons less coal than the "Pottinger," and performed the same distance in 68¼ hours less time. This result of diminished consumption is undeniably a fair triumph for the Improved Boiler; as for the improved speed of the vessel, it must share the honours with the feathering paddle wheel; the "Bentinck" has made the fastest passage on record between the ports mentioned.

In conclusion, the author can only say that he believes the Improved Boiler described in the present paper will become the Marine Boiler generally adopted; as its merits are evident, and its cost is not greater than Tubular Boilers; while its durability will, he thinks, be very much greater. He will be happy to show these Boilers to any of the Members of the Institution who may have an opportunity of seeing those that may be in port, or at Mr. Summers' Works at Southampton, where there are now five sets in course of construction. It may be added that the screw steam ship, "Glasgow," by Messrs. Todd and Mc Gregor, which has lately made the fastest run across the Atlantic of any screw steamer, is fitted with these Improved Boilers; Messrs. Todd and Mc Gregor have made a considerable number of them, and they are also being manufactured by several others. It is intended also to adopt these boilers in the "Himalayah," now building for the Peninsular and Oriental Co., of upwards of 3000 tons burthen, to be propelled by oscillating engines of 1200 horse-power.

[*Note.*—The details of construction of the flues are shown in Figs. 4, 5, and 6, Plate 49; Fig. 4 is a transverse section, Fig. 5 a plan, and Fig. 6 a longitudinal section of a portion of the flues AA, shown on an enlarged scale. They are constructed of two flat side plates GG, ⅜ inch thick, flanged outwards at each end to meet the plates of the adjoining flues; the top and bottom of each flue is formed by the curved connecting piece HH, which is rivetted to each side plate, and flanged outwards at the ends. The stays or studs BB, are 1⅛ inch diameter, and are rivetted at each end through the side plates. The rivets connecting the plates together, and the stays, are all put into their holes simultaneously, and rivetted cold by machinery. These rivets have countersunk heads and points, and when placed in their holes in the plates a steel bar is inserted, which fills up the space between the heads of the two rows of rivets, and acts as a bolster to the rivetting tool. By this means one stroke of the machine closes two rivets at once, and in the most efficient manner. The flues are afterwards rivetted

together with covering strips I I at their ends, and they are inserted into the boiler in sets of seven or eight, according to the size of the furnace.

Any one of the flues can be readily extracted from the others if necessary, by cutting away the two rows of rivets at each end, and drawing it out through the front smoke-box doors E. The experience which they have had of the durability of the flues has, however, satisfied those who have employed them, that unless gross negligence of the engineer should (through want of water) allow them to get red hot, the flues will in all cases outlive the shells in which they are inserted.]

The CHAIRMAN observed, that he regretted Mr. Lamb was not able to be present on that occasion, to have given them further practical information on the construction of the boiler that was desirable. He had not explained in the paper the mode of fixing the flue-plates to the boiler at each end, and the mode of removing and replacing the flues when required.

Mr. SHANKS said he had seen some of the boilers on that plan making at Glasgow, but was not acquainted with the practical details.

Mr. E. JONES thought there would be some practical difficulty in removing and replacing the flue-plates without disturbing the boiler.

The CHAIRMAN remarked, that the question of principle in the boiler was one of heating surface, and there was certainly a considerable advantage in having only the small horizontal surface at the bottom of the flues for the deposit to collect upon, and the vertical position of the plates allowed the freest fall for the deposit to the bottom.

Mr. COWPER said the construction of the boiler reminded him of Hancock's boiler, which was invented for common road locomotives; that boiler consisted of a number of very thin flat chambers, with a number of stays passing through all the chambers, which were in tension instead of compression as in Mr. Lamb's boiler: these stays passed through a series of ferules, or very short tubes, forming struts both inside the chambers and

between them. The boiler was very complicated, from having so great a number of joints, and was consequently very troublesome to keep steam-tight; but it was a very effective plan for generating steam, and very economical of space; the air came away from the flues as cool as in a locomotive chimney. A short narrow flue is equal to a long wide flue, as in the large flue boilers, for extracting the heat out of the air passing through it, as the whole of the air is brought so much sooner in contact with the sides of the flue.

Mr. MIDDLETON said that the boiler described in the paper reminded him of another boiler somewhat similar to Hancock's, where there was great difficulty in keeping it steam-tight. The bottom of the flues was not considered so good a heating surface as the top of the flues, and therefore in Mr. Lamb's boiler the whole of the sides of the flues should not be calculated as efficient heating surface: he thought two thirds would be enough to take.

Mr. COWPER observed, that would be merely a question of what value was put upon the heating surface per square foot. But there would be more loss from that cause in tubes than in Lamb's flues, as the bottom surface of each tube amounted to a fourth or more of the whole heating surface; but in Lamb's boiler the bottom surface of the whole flue was only equal to the bottom of one tube.

The CHAIRMAN considered it desirable to obtain further particulars from Mr. Lamb respecting the boiler, and its relative evaporating efficiency as compared with the ordinary tubular boiler.

Mr. SHANKS said, that Messrs. Todd and McGregor had last year built for the Peninsular and Oriental Co., two vessels exactly the same in every respect, except that one had tubular boilers and the other Lamb's flue boilers: they were both, he believed, performing their voyages in the Indian ocean, and they would supply an excellent means of making a comparison between the two constructions of boilers, and he hoped Mr. Lamb would report the results of this trial to the Institution.

Mr. ALLAN suggested, that the flues might be put in with a

flange all round at each end, like the mid-feather in a locomotive firebox, and fixed by two rows of rivets down each water space. The rivet heads might then be readily cut off all round any one flue, and the flue taken out, when required; and a new flue might then be inserted, by reaching down the water spaces between the flues to put the rivets in.

Mr. Cowper observed, that he had once been told by Mr. Preston, of Liverpool, of a tubular boiler of ordinary construction in a steamer on the Mersey, which did not make steam enough; and he found on examination that the tubes were all set solid together with the deposit formed between them, so much so, that he cut off all the tubes at each end inside the tube-plates, and took them all out in one mass.

Mr. Shanks said, he remembered the boilers of the "Caledonia" steamer, after seven years' work across the Atlantic, were found to be still in good condition, and with very little scale upon them; they were common flue boilers, and were kept clean chiefly by the constant use of the brine pump. He enquired whether, in stationary boilers, Ritterbandt's plan of using muriate of ammonia did not prevent incrustation?

The Chairman observed, that Ritterbandt's process only removed the carbonate of lime, but did not act on the sulphate, which formed a large portion of the deposit.

Mr. Cowper said, he remembered trying that plan in a pair of stationery engine boilers, but after finding that it caused the engines to get quite rusted, the plan was abandoned.

The Chairman proposed, that the discussion on the boiler should be adjourned, and Mr. Lamb be requested to give them the further information respecting it at the next meeting; he proposed a vote of thanks to Mr. Lamb for his communication, which was passed.

The following paper, by Mr. William Handley, of London, was then read :—

ON AN IMPROVED BREAK FOR RAILWAY CARRIAGES.

A great variety of Breaks have been invented for stopping Railway Carriages, but nearly all of them act upon the same general principle, and are simply different methods of pressing blocks of wood against the circumference of the wheel, so as to stop its revolution, and cause the tire to slide upon the rails.

If the wheels are all stopped, the friction of the weight of the carriage sliding upon the rails is the whole amount of breaking power that can be obtained by any of the plans, and the different methods used to accomplish this add no power for stopping the carriages, but are only different ways of pressing the break-blocks against the tires, for the purpose of insuring greater rapidity, certainty, and uniformity of action, reducing the expenses of repairs, and the jarring on the carriages—or to make the breaks self-acting, or worked in combination.

The principal object to be obtained is to have the blocks always pressed square against the wheels, and with a uniform pressure on all the wheels of the same carriage or waggon, &c.; unless this is effected there is great difficulty in stopping the wheels, and much straining is caused upon the carriage. In the earlier breaks the block is suspended by a vertical lever from the frame of the carriage or waggon, &c., as shown at C in Fig. 1, Plate 50, the block A being shaped to the circle of the wheel, but the varying height of the frame of the carriage, from the variation in the weight of load acting on the springs, causes much inequality in the fitting of the break-block to the wheel, from the relative level of the break block and the wheel being changed, as shown by the dotted line, B B; also, the action of the springs is stopped by the pressure of the break, causing violent jarring and concussions, injurious both to the carriage and the road, and being very annoying to passengers.

The slide break, shown in Fig. 2, was invented for the purpose of remedying these defects. The relative level of the wheel and the break-block is preserved unchanged, by the break-block, A, sliding horizontally upon a bar, B B, which is carried by the axle-boxes at each end, C; a difficulty is experienced, however, in preserving an equal

pressure on all the break-blocks, on account of the unequal wearing of the different bearings.

All the above breaks have, however, the serious objection that flat places are worn upon the tires of the wheels, by sliding upon the rails, and the wheels consequently become, to a certain degree, polygonal. Any deviation from the circular form of the wheel becomes a serious source of injury both to the rails and the wheel, from the amount of concussions caused by the great velocity of rolling, and the great weight carried; this also causes increased expense in the wear of the tires and rails.

Fig. 3, Plate 50, shows another break, invented by Mr. Lee, in 1842; the wooden break-block, A, is made of a triangular form, and is pressed both against the wheel and the rail by the lever, B, which is centred upon the nave of the wheel, C, by means of a ring or collar fitting in a circular groove cut round the nave; the rubbing face of the wood block is shod with copper or iron. The connecting rods, D D, have adjusting screws, to preserve the relative position of the break-block, A, and the wheel, as the surface of the block wears away.

The mechanical arrangement of this break, it will be perceived, does not admit of sufficient pressure being applied against the wheel and the rail to form an efficient break; but even if the pressure were sufficient to stop the wheel, the same objection would still apply as in the ordinary break, namely, flat places would be worn on the wheel. This break was tried on one or two railways, but has not come into use.

Fig. 4 shows a break on an entirely different principle, brought out by Mr. Adams, in 1847; this consists of a sledge, A A, sliding upon the rails, upon which the whole weight of the carriage is thrown by lifting the wheels off the rails. The sledge A A is a long piece of iron, with a flange at each end to guide it on the rails, and is suspended by two links, B B, from the iron bar C C, which is supported by the links D D, and bears against the under side of the axle-box at each end, E E; the links B B are in the form of a parallel rule, and when they are straightened by the action of the lever, the sledge A A is pressed upon the rails, and lifts up the wheels from their bearing on them. This break saves the wheels from being worn flat; but it requires great power to put the whole weight of the carriage upon the sledge, and is

consequently slow in action; and there is also an objection to it in having the wheels hanging without any support when the break is in action. It has not come into use in England, but there were several breaks on the same principle in use in Belgium for some time previously.

Handley's Improved Break, the subject of the present paper, is shown in Figs. 5 and 6, Plate 51. This break is on the same principle as the ordinary skid used on common roads; the two iron arms, A A, are carried by the axle, B, upon which a brass ring, H, is fitted, turning round the axle; and at the ends of these arms are fixed the shoes or skids, C C, one of which is made to pass under the wheel, whichever way the carriage is running, raising it from the rails by turning the lever round upon the axle. The shoe is made the breadth of the tread of the wheel, without any flange, and the wheel is lifted only about one eighth of an inch on the average, so that the flange of the wheel continues as efficient and secure a guide upon the rails as in the ordinary case of a wheel stopped from revolving by the pressure of a break-block. The shoe is made in two pieces: the upper one, C, is forged on to the arm A, and the lower piece, D, which forms the skid, is hinged to it at the end. The object of this construction is to prevent the shoe from touching the wheel until it is required to be put in action; the joint opens about a quarter of an inch, and the shoe falls away from the wheel when it is lifted, being stopped by the bolt E, which limits the extent of its opening; and round this bolt is placed a short spiral spring, to keep the joint open, and prevent it from shaking when the carriage is running.

The wear of the shoe is provided for by inserting two small dovetailed pieces, F and G, at the points where the wear takes place; these pieces are slightly tapered, and are driven into their places from the inner side, being burred or rivetted on the opposite side, where they remain firmly fixed, having no tendency to work loose. The lower piece is of wrought iron, which is found to answer best for the purpose; the upper one, F, which carries the wheel, is of cast iron: it has very little wear upon it, but is changed occasionally for a piece of greater thickness, to allow for the wear of the shoe-plate G, and preserve the total thickness of the shoe, within very little variation, so as to prevent much difference in the height that the wheel is lifted from the rails.

This break is easily and quickly applied, by means of the lever, L, acting on the upper arm of the break, K, as the carriage runs upon the shoe when it is pressed under the wheel; it requires less force than the ordinary break, and is put on more quickly. The ordinary break screw, lever, and cross shaft, are available for working this break.

This mode of breaking has the advantage of keeping the wheels perfectly circular, and preventing them wearing polygonal, which under the ordinary mode converts them, in fact, into so many hammers beating upon the rails, to the no small detriment of the permanent way.

As the wheels rest upon the skid, which slides along the rail, the axles are saved from that strain and torsion which necessarily arise when blocks are pressed with great force against the wheels to stop them. Instances often occur of the axles of break carriages failing from this cause.

When wheels are stopped with the ordinary break, the surface bearing upon the rails is so small that it follows into the soft and hollow places of the rails, and makes them worse; this shoe, however, having a bearing of sixteen inches, passes over them, and saves the rails from that wear.

In consequence of the axle being taken for a bearing, and the pressure being downwards, in the same manner as when the wheel is running, the action of the springs is not in the least interfered with, and the carriage runs as easily, and without any jar, when the break is put on as when it is off. The wheels are also kept quite cool, saving the tires thereby from expansion.

The retarding power of this break is found to be greater than that of any of the ordinary breaks, both in dry weather or when the rails are slippery; and it is found from experience that two pairs of wheels with this break are about equal to three pairs with the ordinary break.

In all the breaks where the wheel itself forms the shoe or skid, the weight of the carriage is carried on the small point of contact of the wheel, which immediately wears bright and clean, and the friction is thereby materially diminished; but in this break the much greater extent of surface in contact prevents it from getting rubbed clean and bright, and the particles of grit are retained between the rubbing surfaces, causing increased friction.

Several of these breaks are in use on the Eastern Counties Railway,

on break vans, and also applied to one pair of wheels of some tank engines running on branch lines; and they have worked constantly with entire satisfaction, from half a year to a year, working daily over the points and crossings of the stations, without any difficulty or accident having been experienced.

A break van, fitted with these breaks, has been running in a goods train for two years, averaging 700 miles weekly, and the shoe-plates put in six months since, still remain good. The shoe-plates of the tender breaks last about three months before requiring renewal, and those of the tank engines about two months.

The CHAIRMAN observed, that they were disappointed of Mr. Handley's presence, who was to have attended at the meeting; and in his absence the Secretary, Mr. Marshall, who had mainly prepared the paper and drawings, would afford any further explanation on the subject that might be required.

Mr. Adams said, he considered a sledge break was undoubtedly better than the ordinary plan of sliding on the wheel, if the practical objections and difficulties could be overcome, but he had never seen Mr. Handley's break before, nor a drawing of it. It would depend on the results of working, whether safely and satisfactorily; but he thought it would require much force to put on the break and lift the carriage.

The SECRETARY explained that the wheel mounted up the inclined point of the sledge by running in that direction, and that it was found not to require more force at the handle to put it on or take it off than the ordinary break; it was worked by a screw and lever in the ordinary manner, and $2\frac{1}{2}$ turns of the handle were sufficient to put it on. In taking off the break it required a pinch at first to loosen the shoe, and then the weight of the carriage assisted in getting the wheel off.

Mr. HENSON thought the break was an ingenious principle, but did not quite approve the application; and he thought the ordinary breaks would afford more retarding power when they were made not quite to stop the wheels. A good breaksman knew

that by keeping the break-block pressed against the wheel with a little less force than would stop the wheel from revolving, he could produce a greater friction than by skidding the wheels.

Mr. Clift doubted the durability of the bottom shoe-plates, and thought they would be continually wanting to be renewed, which would involve great practical inconvenience and expense.

Mr. Adams observed that there was a great trouble and expense with the present breaks, in constantly changing the wood break-blocks, which wore out in a very short time where there was much work to be done. If the whole weight of the carriage were sledged, that must be the limit of breaking power, but it was clearly a bad mechanical arrangement to sledge it on the mere points of contact of the wheels on the rails.

The Secretary explained the provision made for changing the shoe-plates; these plates were all alike, planed to one gauge, with the same taper, so that each one would fit any break, and a stock of them was kept always ready, and any plate could be changed in a few minutes. The cost of these pieces of iron was very little, and they appeared to have great durability, those under the break-vans lasting more than six months.

Mr. Peacock was not acquainted with the break before, but he certainly thought it was an exceedingly good scheme, and well carried out. He enquired about the construction of the brass collar that carried the break upon the axle—whether it was fixed tight on the axle, or the axle revolved in it? he doubted whether it would last long, from the friction upon it.

The Secretary explained that the brass collar was fixed in the break, and turned loose on the axle; it was consequently always rubbing whilst the carriage was running, but the friction was very small, as the only pressure upon it was the weight of the break itself, which was suspended by the brass collar. When the break was in action there was no friction, as the axle was then stationary. A specimen was exhibited of one of these brass collars, $1\frac{3}{4}$ inch wide and $\frac{3}{16}$ inch thick, which had been six months at work in a break, but showed very little signs of wear.

Mr. GOODFELLOW did not understand how the wheel was prevented from mounting farther on to the shoe than was intended, and rolling over it; he thought it would be only prevented by the small bolt connecting the upper and lower pieces of the shoe, and that a stop was wanted for the arm of the break, to prevent it from moving too far.

The SECRETARY said that he believed a stop was provided for the break in the Tank Engines by making one of the arms of the break work inside a segment, which limited its motion both ways; but that there was no other stop in the break vans than the screw of the break handle, which was sufficiently powerful to pull back the break whilst the carriage was travelling forwards, and would, therefore, have power enough to hold the break from going farther under the wheel. The bolt connecting the pieces of the shoe was free, and had no strain upon it when the break was in action, as the two pieces were then pressed close together; but supposing the handle detached, the wheel could not pass over the shoe without tipping up on the front end of the shoe, as a centre, which was a long leverage.

Mr. COWPER remarked that if the proportion between the height of the axle from the rail, and the length of the base upon the rail from the centre of the wheel to the front end of the shoe, was only the same as the proportion between the total weight on the wheel, and the sliding friction on the rail, then the wheel would be just on the point of rolling over the shoe; but if the proportionate length of the base upon the rail exceeded the limit of the sliding friction, the shoe must slide forward, and the wheel could not roll over it even if the break arm were loose from the handle, and free to revolve round the axle. In the drawing of the break, the angle at the front of the shoe appeared to be about 45°, so that the base on the rail was equal to the height, and the friction could never be sufficient to prevent the shoe from sliding forward; nothing but a fixed obstacle could do so.

Mr. ADAMS considered the break must prove very economical, if it was found efficient in practice, from saving the extra

expence of repairs of the wheel tires, which was very great on lines with steep gradients, where the breaks were required to be in very frequent use. He wished to ask Mr. Peacock what he found the expence of keeping in repair the wheel tires of the break vans.

Mr. Peacock said that in the long steep inclines of the Manchester, Sheffield, and Lincolnshire Railway, they had the wheels of the break vans and tenders skidded for three or four miles together sometimes, and the wheel tires were worn out very rapidly in consequence; the men could not be prevented from skidding the wheels, where they had the power of doing so, by the break. The wheels required taking out and turning up about once in two months, and this process generally answered only twice, after which new tires were required; the cost of renewing the tires was about £10, and £2 more might be added for the intermediate turnings up and the cost of changing.

Mr. Adams observed that the annual expence caused by the wear of the wheel tires alone in the break waggons appeared, therefore, to exceed £15 per waggon, under the present system, and the consequent saving would be very important in that item alone, in a large stock of waggons, by the use of the new break preventing the polygonal wear of the wheels.

Mr. Cowper said he thought there was some objection to pushing a sledge in front of the wheels, in case of its catching against any fixed obstruction, such as a bad joint in the rails; although it was rounded off at the front end, it would wear into a flat surface, making an angle; but when a wheel was skidded it always presented a rounded surface to any obstacle; and if the obstacle did catch it, it only turned the wheel round a little.

The Secretary observed, that the shoe was made with a long gradual slope at the end, and however worn at the bottom, it would always leave so easy an angle in front as to pass over any joint as well as a skidded wheel could.

Mr. Goodfellow thought that a side wear of the flange of the wheel might be found to take place, particularly in passing round curves, which would wear out the tire, although the head

of the tire was not subjected to wear; and he doubted whether there was sufficient guide on the rail.

Mr. PEACOCK observed that the break-shoe might be made with a flange, which would obviate any wear on the flange of the wheel.

The CHAIRMAN remarked that it was an interesting and important subject, and this break was certainly a very ingenious invention, well deserving of a complete trial.

He proposed a vote of thanks, which was passed, to Mr. Handley, for furnishing them with the information, and to the Secretary for preparing the communication, which was passed.

The following paper by Mr. James Samuel, of London, was then read:—

ON A CONTINUOUS EXPANSION STEAM ENGINE.

THE economy of working steam expansively is well known, but the application of the expansion principle is practicable only to a limited extent in most forms of engine, from practical difficulties in their mode of working which prevent the attainment of the full economy of which the expansive principle is capable.

The greatest useful effect is obtained from the steam, when it is allowed to expand in the cylinder until its pressure upon the piston just balances all the useless resistances of the friction of the engine itself, and the resisting pressure on the back of the piston; (whether the pressure of the atmosphere, in a high-pressure engine, or of the uncondensed vapour, in a condensing engine,) the surplus power beyond these useless resistances being alone available for the purposes to which the engine is applied.

But in driving machinery, so great a uniformity of motion is essential, that any great variation in the moving power throughout the stroke of the engine is inadmissible, as the flywheel would not be able to absorb enough of the excess of power to equalise the velocity sufficiently, by giving it out again at the deficient part of the stroke; consequently, though two engines are often employed working at right angles to each other, for the purpose of diminishing the variation in

total moving power, the expansion principle can only be carried to a portion of the extent to which it is theoretically applicable.

Only in such engines as the large Cornish pumping engines can the expansion be carried practically to its full theoretical limit, as the variation in the velocity of the load moved is of much less importance in those engines, and the very unequal amounts of moving power that are developed in equal times, by the full carrying out of the expansive principle, which would produce the most prejudicial and inadmissible variations of velocity in the engine, are controlled within prescribed limits by the great weight of material to be moved by the engine in the pump rods and balancing machinery, forming as it were a distributing reservoir for the moving force developed.

In the Locomotive Engine there are practical difficulties in carrying out the expansion principle efficiently, beyond a moderate extent, in a single cylinder, from the shortness of stroke and rapidity of reciprocation, and the construction of the valve motion; but the ultimate extent to which it could be carried would be limited by the maintenance of the blast, which requires that the jets of steam discharged from the cylinder into the blast-pipe should not be reduced below a certain pressure at the moment of discharge. Otherwise, the limit to which expansion might be carried would be the resistance of the atmosphere to the discharge of the steam, added to the friction of the engine, say about 10 lbs. per inch above the atmosphere.

The steam is cut off usually by the link motion at from $\frac{1}{3}$rd to $\frac{2}{3}$rds of the stroke, and the steam is consequently discharged into the blast pipe at about from 30 to 60 lbs. pressure above the atmosphere, supposing it to be supplied to the cylinders at 100 lbs. per inch above the atmosphere.

It appears that the lower of these pressures is sufficient, or more than sufficient, for the purposes of the blast, to maintain fully the evaporative power of the boiler under general circumstances, and that a portion of the steam discharged can be spared from the blast to be subjected to a greater extent of expansion.

In the Continuous Expansion Engine, the subject of the present Paper, the steam from the boiler is supplied only to one cylinder; a portion of it is expanded into the second cylinder, which is of pro-

portionately larger area, so as to equalise the total moving power of the two cylinders; and it is there further expanded down to the fullest useful extent, and then discharged into the atmosphere, the portion of steam remaining in the first cylinder being discharged as a blast at nearly the same pressure as the ordinary engines. The economy, therefore, consists in obtaining from such portion of the steam as can be spared from the blast the additional power of expansion remaining in it, which is thrown away in the ordinary engine.

Figs. 1 and 2, Plate 52, show the Continuous Expansion Engine as applied to a Locomotive. A is the first cylinder into which the steam is admitted from the steam-pipe, C, by the valve D, in the same manner as in the ordinary engines. The steam is cut off at half stroke, and a communication is then opened with the second cylinder, B, through the passages H and F, by the opening of the slide valve G. The second cylinder, B, is about double the area of the first cylinder, and the same length of stroke, but the cranks are set at right angles, as in ordinary locomotives; consequently, at the moment of the steam being passed into the second cylinder from the first, the piston of the second cylinder is at the commencement of its stroke.

The steam continues expanding in the two cylinders, until the first piston, A, has nearly completed its stroke, when the valve, G, shuts off the communication between the two cylinders, and the valve, D, opens the exhaust port, and communicates with the blast-pipe, L, discharging the steam remaining in the cylinder, A, to form the blast in the ordinary manner. The second piston, B, has then arrived nearly at half stroke, and contains nearly one half of the total quantity of steam originally admitted to the first cylinder; this steam is further expanded to the end of the stroke, and then discharged into the blast pipe, L, by the valve, E, opening the exhaust port.

The return stroke of both pistons is exactly similar to the foregoing, so that about $\frac{1}{2}$ cylinder full of high-pressure steam (or such other portion as may be desired) is supplied to the first cylinder at each stroke, and between $\frac{1}{2}$ and $\frac{2}{3}$rds of that steam is discharged at the pressure required to produce the blast, and the remainder of the steam is expanded down in the second cylinder, so as to give out all the available power remaining in it.

For the purpose of enabling the engine to exert an increased power,

if required, at the time of starting a train or otherwise, the slide valve, I, is inserted in the centre passage, F, to close the communication between the two cylinders for a short time when required; and the steam from the boiler is then admitted by a pipe and cock into the steam-chest of the second cylinder, B, which is then worked independently of the other cylinder, like an ordinary engine.

The comparative quantity of steam or of coke required to perform the same work in the several engines, under the circumstances stated above, is given by calculation as follows:—

Continuous Expansion Engine			. . . . . .	100
Ordinary Engine, cutting off at			$\frac{1}{3}$rd stroke . .	120
Ditto	ditto,	ditto	$\frac{1}{2}$ stroke . .	154
Ditto	ditto,	ditto	$\frac{2}{3}$rds stroke . .	185
Ditto	ditto,	ditto	$\frac{7}{8}$ths stroke . .	220

These figures represent the relative economy in the employment of the steam in the several engines; consequently, the ordinary Engine, with the best degree of expansion, or cutting off the steam at $\frac{1}{3}$rd of the stroke, consumes 20 per cent. more coke than the Continuous Expansion Engine, to do the same work, and from 54 to 85 per cent. more coke with the more usual degrees of expansion; and an Engine cutting off the steam at only $\frac{1}{8}$th of the stroke from the termination, as many engines were formerly made, would consume 120 per cent. more coke to do the same work.

This plan has been tried upon two locomotives with satisfactory results, and the blast was found to be quite sufficient, but the trial has not been sufficiently complete to afford a definite comparison of consumption.

In the application of the Expansion principle to Stationary Engines, it is requisite to consider the amount of variation in the moving power or labouring force of the engine, and the limits within which it is necessary practically to confine this variation. The accompanying diagrams, Figs. 3, 4, and 5, Plate 53, show the variation in the moving power that takes place between the commencement and the end of the stroke in each of the several engines, all drawn to the same scale and on the same principle, so that the comparison of the diagrams will show

the relative effect of the steam in the several engines; the same total power being represented in each case.

Fig. 3 shows the variation of power in the Cornish engine, when the steam is expanded down to the limit of useful effect; this is shown by the curved line, A G C. The vertical height of the first division, A D, represents the relative total moving force developed by the engine, in the direction of the revolution of the crank pin, during the first 15° of revolution from the commencement of the stroke. The heights of the succeeding divisions in Fig. 3 represent the corresponding amounts of force developed by the engine during each successive motion of the crank, through equal angles of 15° each to the end of the stroke, C, and the half revolution of 180°; the force shown being in all cases the amount that would be produced in the circular direction of the revolution of the crank pin, not in the rectilinear direction of the piston. If the amounts of force in these several divisions were all exactly *equal to one another* (and the engine having attained its state of uniform velocity, were employed to overcome a constant resistance to circular motion, such as driving a corn mill or spinning mill, &c.), then the crank arm would have a perfectly unvarying velocity, and no fly-wheel would be required. And the approach to this constancy of velocity, in any engine applied to overcome resistances to circular motion, will clearly depend on the approach to equality which these amounts of work produced through equal angles make to one another.

The average line, DE, shows this average equal height of all the several divisions, consequently the rectangle, ACED, represents the equivalent uniform development of power that would produce an unvarying velocity of rotation, and therefore the area of the shaded space being the deficiency in filling up this rectangle of uniform power by the actual working of the engine (also equal to the portion H of the curved figure that is above the average line, DE), will represent the total amount of variation from the average in the moving force of the engine throughout the stroke. The area of the shaded portion in this diagram is 43 per cent. of the total area, consequently the *total variation* from the average in the moving power of the Cornish engine is 43 *per cent.*, and the *greatest variation* at the extreme point G, amounts to 189 *per cent.* of the mean power.

The total variation from the average power . 43 per cent.

The extreme variation . . . . 189 per cent.

Fig. 4 shows in a corresponding manner the variation of moving power throughout the stroke in the Continuous Expansion Engine, where the steam is cut off at half stroke in the first cylinder, and expanded in the larger cylinder down to the limit of useful effect.

The total variation from the average power is only . 13 per cent.

The extreme variation . . . . 55 per cent.

consequently the *total variation* in the moving power in the Cornish Engine is $3\frac{1}{3}$ *times* as great as that in the Continuous Expansion Engine, and the *extreme variation* is $3\frac{1}{2}$ *times* as great.

The dotted line, B B, in Fig. 3 shows the effect of coupling together two Cornish engines, exactly similar to that shown by the full line in Fig. 3, but of half the total power each.

The total variation from the average power is . . 20 per cent.

The extreme variation . . . . 58 per cent.

the *total variation* in the moving power being $1\frac{1}{2}$ *times* as great as in the Continuous Expansion Engine, and the *extreme variation* about equal. This arrangement would of course be much more expensive than the Continuous Expansion Engine, as it involves two complete engines.

Fig. 5 shows the variation of moving power in a Woolf's double cylinder engine, where the pistons work simultaneously in the two cylinders, commencing each stroke together, and the steam is cut off at half stroke in the first cylinder, and afterwards expanded in the larger cylinder down to the limit of useful effect, as in the foregoing Cornish Engine.

The total variation from the average power is . 27 per cent.

The extreme variation . . . . 90 per cent.

conseqently the *total variation* in the moving power is 2 *times* as great as in the Continuous Expansion Engine, and the *extreme variation* $1\frac{3}{4}$ *times* as great.

The dotted line, FF, on Fig. 4 shows the effect of coupling together two of the Continuous Expansion Engines at right angles to each other, and the result of this arrangement is a remarkably near approach to perfect uniformity of moving power.

The total variation from the average power is only . 3 per cent.

The extreme variation . . . . 8 per cent.

The dotted line, F F, on Fig. 3 shows in a similar manner the effect of coupling together three of the Cornish Engines with cranks at 120° to each other.

The total variation from the average power is . . 9 per cent.
The extreme variation . . . . 22 per cent.
both being about 3 *times* as great as in the Continuous Expansion Engine.

Fig. 5 shows also by the dotted line, F F, the effect of coupling together two of the Wolf's Engines at right angles to each other.

The total variation from the average power is . . 5 per cent.
The extreme variation . . . . 13 per cent.
both being about 1½ *times* as great as in the Continuous Expansion Engine.

The comparative amount of work performed by the several engines, with the same quantity of steam or of coal in each case, under the circumstances stated above, and taking the pressure of the steam admitted to the first cylinder at 50 lbs. per inch above the atmosphere, is given by calculation as follows:—

Continuous Expansion Engine	100
Woolf's Engine	109
Cornish Engine	111

The general result of the above comparisons is, that the *Cornish Engine is* 11 *per cent.*, and *Woolf's Engine is* 9 *per cent.*, *more economical* in expenditure of fuel than the *Continuous Expansion Engine*, when the expansion of the steam is carried to the *extreme limit* in each case; but that this economy cannot be obtained practically in those two engines, on account of the great irregularity in their moving power, the *average irregularity* being, in the *Cornish Engine* 30 *per cent.*, and in *Woolf's Engine* 14 *per cent.*, *greater* than in the Continuous Expansion Engine; and the *extreme irregularity* being 134 *and* 35 *per cent.* respectively *greater*.

Consequently it appears that, although the expansion of the steam cannot be *theoretically* carried to so great an extent in the Continuous Expansion Engine as in the other engines, yet, from the moving power being so much more uniform throughout the stroke, the expansion can be carried *practically* to a considerably greater extent; and a

greater amount of economy may be practically obtained within the same limit of uniformity in the moving power.

A working model, one third size, of the engine as applied to a Locomotive, was exhibited to the Meeting.

Mr. E. JONES observed that the engine appeared to be a step quite in the right direction, but further practical trial was requisite.

Mr. PEACOCK wished to know the particulars of the trials that had been made.

The CHAIRMAN suggested that the discussion should be adjourned to the next meeting, as Mr. Samuel, who had intended to be present, was unexpectedly prevented from attending. He proposed a vote of thanks to Mr. Samuel, which was passed.

The CHAIRMAN announced that Mr. Prosser, of Birmingham, had kindly sent, for the inspection of the Members, the portrait of Papin that was exhibited to the Meeting.

The Meeting then terminated; and in the evening a number of the Members and their friends dined together, according to custom, in celebration of the fifth Anniversary of the foundation of the Institution.

Mr. GEACH announced that the Committee formed for carrying out the Monument to the late George Stephenson, had made final arrangements to erect a marble statue in the centre of the large entrance hall, at the Euston Station, as the metropolitan terminus of the system of railways of which he had been the originator. The Directors of the London and North Western Railway had kindly given their sanction to this proposal, which had met with general approval amongst the Subscribers, and the Committee had obtained subscriptions amply sufficient to carry out the intention. A very gratifying feature in the subscription was, the large number of working mechanics who had joined in promoting the object.

SUBJECTS FOR PAPERS.

Steam Engine Boilers, particulars of construction—form—heating surface—cost—consumption of fuel—evaporation of water—pressure of steam—steam gauges, high pressure and low pressure—explosion of boilers, and means of prevention—effects of heat on the metal of boilers, low pressure and high pressure—incrustation of boilers, and means of prevention—evaporative power and economy of different kinds of fuel, coal, wood, charcoal, peat, patent coal, and coke—moveable grates—smoke consuming apparatus, best plan and results of working.

Steam Engines, expansive force of steam, and best means of using it—power obtained by various plans—comparison of double and single cylinder engines—comparative advantages of direct-acting and beam engines—indicator figures from engines, with details of useful effects, consumption of fuel, &c.—contributions of indicator figures for a general book of reference to be kept in the Institution.

Pumping Engines, particulars of various constructions—size of cylinder, strokes per minute, and horse power—number and size of pumps, and strokes per minute—application of pumps—fen draining engines—comparative advantages of scoop wheels and centrifugal pumps, &c.

Blast Engines, best kind of engine—size of cylinder, strokes per minute, and horse-power—number of boilers—size of blowing cylinder, and strokes per minute—means of regulating the blast—improvements in blast cylinders—rotary blowing machines.

Marine Engines, power of engines in proportion to tonnage—different constructions of engines—comparative economy and durability of different boilers, tubular boilers, flat flue boilers, &c.—weight of machinery and boilers—kind of paddle wheels—speed obtained in British war steamers, in British merchant steamers, and in Foreign ditto, with particulars of the construction of engines with paddle wheels, &c.—screw propellers, particulars of different kinds, number of arms, material, means for unshipping, horse-power applied, speed obtained, section of vessel.

Rotary Engines, particulars of construction and practical application—details of the results of working.

Locomotive Engines, express, passenger, and luggage engines—particulars of construction, details of experiments, and results of working—speed of engines, cost, power, weight, steadiness—consumption of fuel—heating surface, length and diameter of tubes—experiments on size of tubes and blast-pipe—comparative expense of working and repairing—best make of pistons, valve gear, expansion gear, &c.

CALORIC ENGINES, and Engines worked by Gas, Gun-cotton, or other explosive compounds.

ELECTRO MAGNETIC ENGINES, particulars and results.

WATER WHEELS, particulars of construction and dimensions—form and depth of buckets—head of water, velocity, per-centage of power obtained—turbines, construction and practical application, power obtained, comparative effect and economy.

WIND MILLS, particulars of construction—number of sails, surface and form of sails—velocity, and power obtained—average number of days' work per annum.

CORN MILLS, particulars of improvements—power employed—application of steam power—results of working with an air blast and small stones—advantages of regularity of motion.

SUGAR MILLS, particulars of the construction and working—results of the application of the hydraulic press in place of rolls.

SAW MILLS, particulars of construction—mode of driving—power employed—particulars of work done—best speeds for vertical and circular saws—form of saw teeth—saw mills for cutting ship timbers—veneer saws.

OIL MILLS, facts relating to the construction and working, by stampers and by pressure.

COTTON MILLS, information respecting the construction and arrangement of the machinery—power employed, and application of power—cotton presses, mode of construction and working, power employed—improvements in spinning and carding machinery, &c.

MACHINERY for manufacturing Flax, both in the natural length of staple and when cut.

ROLLING MILLS, improvements in machinery for making iron and steel—mode of applying power—steam hammers—piling of iron—plates—fancy sections.

STAMPING AND COINING MACHINERY, particulars of improvements, &c.

PAPER MAKING AND PAPER CUTTING MACHINES, ditto ditto.

PRINTING MACHINES, ditto ditto.

CALICO PRINTING MACHINERY, ditto ditto.

WATER PUMPS, facts relating to the best construction, means of working, and application—best forms—velocity of piston—construction of valves.

AIR PUMPS, ditto ditto ditto.

HYDRAULIC PRESSES, facts relating to the best construction, means of working, and application.

ROTARY AND CENTRIFUGAL PUMPS, ditto ditto.

FIRE ENGINES, ditto ditto ditto.

SLUICES AND SLUICE COCKS, ditto ditto ditto.

CRANES, ditto ditto ditto.

STEAM CRANES, HYDRAULIC CRANES, PNEUMATIC CRANES, ditto.

LIFTS FOR RAISING TRUCKS, &c. ditto ditto ditto.

LATHES, PLANING, BORING, AND SLOTTING MACHINES, &c., particulars of improvements—description of new self-acting tools.

TOOTHED WHEELS, best construction and form of teeth—results of working.

DRIVING BELTS AND STRAPS, best make and material, leather, rope, wire, gutta percha, &c.—comparative durability, and results of working—power communicated by certain sizes.

STRENGTH OF MATERIALS—facts relating to experiments on ditto, and general details of the proof of girders, &c.—girders of cast and wrought iron, particulars of different constructions, and experiments on them—best forms and proportions of girders for different purposes—best mixtures of metal.

DURABILITY OF TIMBER of various kinds—best plans for seasoning timber and cordage—results of Kyan's, Payne's, Bethell's, and Burnett's processes, &c.—comparative durability of timber in different situations.

CORROSION OF METALS by salt and fresh water, and by the atmosphere, &c.—facts relating to corrosion, and best means of prevention.

ALLOYS OF METALS—facts relating to different alloys.

FRICTION OF VARIOUS BODIES—facts relating to friction under ordinary circumstances—friction of iron, brass, copper, tin, wood, &c.—proportion of weight to rubbing surface—best forms of journals, and construction of axle-boxes, &c.—lubrication, best materials and means of application, and results of practical trials—best plans for oil tests.

IRON ROOFS, particulars of construction for different purposes—durability in various climates and situations—comparative cost, weight, and durability—roofs for slips of cast-iron, wrought-iron, timber, &c., best construction, form, and material.

FIRE-PROOF BUILDINGS, particulars of construction—most efficient plan—results of trials.

CHIMNEY STACKS of large size, particulars, mode of building, &c.

BRICKS, manufacture and durability—hollow bricks, fire-bricks and fire-clay.

GAS WORKS—best form, size, and material for retorts—construction of retort ovens—quantity and quality of gas from different coals—oil gas, water gas, &c.—improvements in purifiers, condensers, and gas holders—wet and dry gas meters—pressure of gas, gas exhauster—gas pipes, strength and durability, and construction of joints—proportionate diameter and length of gas mains, and velocity of the passage of gas—experiments on ditto, and on the friction of gas in mains, and loss of pressure.

WATER WORKS—facts relating to water works—application of power, and economy of working—proportionate diameter and length of pipes—experiments on the discharge of water from pipes, and friction through pipes—strength and durabiltiy of pipes, and construction of joints—relative advantages of stand-pipes and air-vessels.

WELL SINKING and ARTESIAN WELLS, facts relating to.

COFFER DAMS and PILING, facts relating to the construction.

Piers, fixed and floating, and Pontoons, ditto ditto.

Pile Driving Apparatus, particulars of improvements—use of steam power—Pott's apparatus—the compressed air system.

Dredging Machines, particulars of improvements—application of dredging machines—power required, and work done.

Diving Bells and Diving Dresses, facts relating to the best construction.

Cast-Iron and Wrought-Iron Lighthouses, ditto ditto.

Mining Operations, facts relating to mining—means of ventilating mines, use of steam jet and ventilating machinery—mode of raising materials—mode of breaking, pulverizing, and sifting various descriptions of ores.

Blasting, facts relating to blasting under water, and blasting generally—use of gun cotton, &c.—effects produced by large and small charges of powder.

Blast Furnaces—consumption of fuel in different kinds—burden, make, and quality of metal—pressure of blast—horse-power required—economy of working—improvements in manufacture of iron—comparative results of hot and cold blast.

Puddling Furnaces, best forms and construction, &c.

Heating Furnaces, best construction—consumption of fuel, &c.

Smiths' Forges, best construction—size and material—power of blast.

Smiths' Fans, and Fans generally, best construction, form of blades, &c., with facts relating to the amount of power employed and the per-centage of effect produced.

Coke and Charcoal, particulars of the best mode of making, and construction of ovens, &c.

Railways—construction of permanent way—section of rails, and mode of manufacture—experiments on rails, deflection, deterioration, and comparative durability—material and form of sleepers, size and distances—improvements in chairs, keys, and joint fastenings.

Switches and Crossings, particulars of improvements, and results of working—advantages obtained by steeling points and tongues.

Turntables, particulars of various constructions and improvements.

Signals for Stations and Trains, and self-acting signals.

Breaks for Carriages and Waggons, best construction.

Buffers for Carriages, &c., and Station Buffers—different construction and materials.

Springs for Carriages, &c., buffing and bearing springs—particulars of different constructions, and results of working.

Railway Wheels, wrought-iron, cast-iron, and wood—particulars of different constructions, and results of working—comparative expense and durability—wrought-iron and steel tires, comparative economy and results of working—solid wrought-iron wheels.

Railway Axles, best description, form, material, and mode of manufacture—comparison of solid and hollow axles.

The Council invite communications from the Members and their friends on the preceding subjects, and on any Engineering subjects that will be useful and interesting to the Institution; also presentations of Engineering drawings, models, and books for the library of the Institution.

The communications should be written on foolscap paper, on one side only of each page, leaving a clear margin on the left side for binding; they should be written in the third person. The drawings illustrating the communications should be on so large a scale as to be clearly visible to the meeting at the time of reading the communication; or enlarged diagrams should be sent for the illustration of any particular portions.

BALANCE SHEET,

For the year ending 31st December, 1851.

Dr.	£	s.	d.	*Cr.*	£	s.	d.
To Subscriptions from 16 old Members in Arrear	48	0	0	By Printing, Engraving, and Stationery	96	16	7
,, ditto from 152 old Members for 1851	456	0	0	,, Furniture for Offices	12	11	7
,, ditto from 19 new Members for 1851	95	0	0	,, Office Expenses and Petty Disbursements	15	18	8
,, ditto from 3 old Graduates for 1851	6	0	0	,, Travelling Expenses	8	9	3
,, ditto from 1 new Graduate for 1851	3	0	0	,, Reporting	17	3	0
,, ditto for 1 Member in advance for 1852	3	0	0	,, Parcels	4	6	0
,, sale of Extra Engravings	3	3	0	,, Postages	26	0	5
,, ditto ditto Reports	5	12	3	,, Salary	343	15	0
,, Balance from 31st December, 1850	230	3	0	,, Rent and Taxes	122	2	7
				,, Balance	202	15	2
	£849	18	3		£849	18	3

(Signed) J. E. CLIFT.
ARCHIBALD SLATE.

26th January, 1852.

PROCEEDINGS.

APRIL 28, 1852.

THE GENERAL MEETING of the Members was held at the house of the Institution, 54, Newhall Street, Birmingham, on Wednesday, 28th April, 1852; ROBERT STEPHENSON, Esq., M.P., President, in the Chair.

The Minutes of the last General Meeting were read and confirmed.

The CHAIRMAN announced that the Ballot papers had been opened by the Committee appointed for the purpose, and the following new Members were duly elected :—

Members :

THOMAS T. CHELLINGWORTH, Oldbury.
SAMUEL H. F. COX, Oldbury.
ROBERT GORDON, Stockport.
JOHN H. PORTER, Birmingham.
JOSEPH W. WILSON, Oldbury.
WILLIAM K. WHYTEHEAD, London.

Honorary Member:

WILLIAM ROBINSON, Birmingham.

The following supplementary paper, by Mr. James Samuel, of London, was then read, in continuation of the paper read at the former Meeting, on January 28th, and adjourned :—

ON A CONTINUOUS EXPANSION STEAM ENGINE.

The object of this invention, as applied to Locomotive Engines, (as explained in detail in the former paper, see Proceedings,

January, 1852,) is to obtain a greater amount of work from the same expenditure of steam or fuel than could be obtained from the present locomotive engines. It was pointed out that the extent to which the expansion of the steam could be carried was limited in the present locomotives, by the necessity of maintaining a certain amount of pressure in the steam at the moment of discharging it into the atmosphere, for the purpose of producing an *efficient blast* to maintain the intensity of the fire. If it were not for this circumstance, which prevented the expansion of the the steam being carried in the cylinders beyond about 30lbs. per inch above the atmosphere, the expansion might be continued nearly down to the atmosphere, and most of the 30lbs. so lost would be then made available as additional power obtained from the same steam. But the author of the paper had found, from experiments, that in the ordinary working, a portion of the discharged steam, probably as much as one-half, could be *spared from the blast*, provided the remainder was discharged at the full pressure of 30lbs., and he therefore retained that portion of the steam in his engine, and caused it to expand nearly down to the atmospheric pressure before it was discharged. This was accomplished by admitting the steam from the boiler only to one of the cylinders of the locomotive, where it was cut off at about half stroke, at which point the second cylinder was just commencing its stroke, (the two cranks being at right angles, as usual,) and a communication was then opened by the slide valve with the second cylinder, which was made from two to three times the area of the first cylinder. The steam was then expanded in both cylinders simultaneously, until the communication between them was closed, and the steam in the first cylinder, was discharged as the blast, whilst that in the second cylinder, which had still half its stroke to perform, was further expanded down to the lowest point of efficiency. By this means, it was shown, a saving in consumption of steam and fuel of 20 per cent. would be effected, compared with the most economical working that could be maintained practically in the present engines, to perform the same work; whilst it would require 120 per cent. more fuel to do the same work with an engine that did not work expansively, and only cut off the steam at one inch from the end of the stroke, as many locomotives were formerly

made. By the second cylinder being enlarged in area in proportion to the difference of average pressure, each cylinder exerted the same total moving power upon its crank, as in the ordinary engines, so that no practical difficulty was experienced; and the steam from the boiler could be admitted direct to the second cylinder by a stop valve for a short time, when required, to give an increased power at starting, or ascending inclines. Two practical trials had been made, which showed that the engines were not deficient in steam from the alteration of the blast, although working the regular passenger and goods trains at full speed. There had not been yet an opportunity for making sufficiently complete experiments to prove the relative economy, but the consumption of fuel was found to contrast favourably with the ordinary engines.

An accurate comparison of the relative amount of duty obtained from the same quantity of steam when employed in these different engines, is shown by the approximate Indicator diagrams, Figs. 1, 2, and 3, Plate 54, which have been carefully drawn out from comparison with actual indicator diagrams, taken from locomotives, so as to allow correctly for the pressure of the exhaust and compression, and the wiredrawing of the valve.

Fig. 2 shows the performance of the steam in an Ordinary Engine, with two 15-inch cylinders = 353·4 square inches area, and 24-inch stroke, cutting off the steam at 8 inches, or $\frac{1}{3}$rd of the stroke, at A. The pressure of the steam is 100 lbs. per inch above the atmosphere, but reduced by wiredrawing to 92 lbs. at the point of cutting off, so that the dotted line AB represents the actual quantity of steam supplied to the two cylinders for one stroke, being 353·4 X 8 inches = 2827 cub. in. at 92 lbs. per inch.

In this case, and in the other two diagrams, the compression C has been made exactly sufficient to fill up the ports and clearance entirely to the full pressure of 92 lbs. steam, for the purpose of simplifying the comparison without interfering with the correctness of the result, so that the steam consumed in each case is exactly equal to the extent of motion of the piston to the point of cutting off the steam.

The steam is exhausted at D, having been expanded down to 28 lbs. above the atmosphere, at which pressure it is discharged as the blast,

The back pressure E is taken at 5lbs. per inch at full speed – say forty miles per hour, from the end of the exhaust to the beginning of compression.

The average positive pressure throughout the stroke	=	63·3 lbs.
,, ,, negative ,, ,, ,,		10·1 lbs.
Total effective pressure . . .		53·2 lbs.

Total Power = 353·4 in. area X 53·2 lbs. per inch = 18,801

Fig. 1 shows the performance of the same steam (2827 cub. in. at 92lbs. per in.) in the Continuous Expansion Engine; the first cylinder is 147·8 sq. in. area, (or about $13\frac{3}{4}$ in. diameter,) and the second cylinder is three times the area = 443·4 sq. in. area (or about $23\frac{3}{4}$ in. diameter.) both being 24-inch stroke, the same as before. The steam is cut off at A, at $16\frac{1}{2}$ inches, or about $\frac{2}{3}$rds of the stroke of the small cylinder. and at D at 1 inch of the stroke of the large cylinder. The dotted lines AB and D, added together, represent the total quantity of steam admitted in each stroke, being equal to the line AB in Fig. 2.

The steam is expanded in both cylinders down to 30 lbs. per inch at the points E and F, 2 inches from the middle of the stroke of the large cylinder, when the communication is shut between the two cylinders, and the steam in the first cylinder is discharged as the blast, amounting to 44 per cent of the whole quantity of steam admitted, and at the pressure of 30lbs.; being a little higher than the pressure of the blast taken in the ordinary engine, Fig. 2, and about half the quantity of steam.

The back pressure G in the small cylinder is taken at 5lbs. per inch, the same as in Fig. 2; but the steam in the second cylinder is further expanded down to 7lbs. per inch above the atmosphere before it is exhausted at H, and reduced nearly to the atmospheric pressure at the end of the stroke, the back pressure I being taken at $\frac{1}{2}$lb. per inch.

		Small Cylinder.	Large Cylinder.
The average positive pressure throughout the stroke	=	87·2lbs.	30·8lbs.
Ditto negative ditto ditto	=	13·8lbs.	4·9lbs.
Total effective pressure . .		73.4lbs.	25·9lbs.

Total Power,

1st cylinder, 147·8 in. area X 73·4lbs. per inch . . .	=	10,849
2nd cylinder, 443·4 in. area X 25·9lbs. per inch . . .	=	11,484
Total . . .		22,333

Then 18,801 : 22,333 : : 100 : 119

Therefore Gain = 19 per cent.

Consequently the power obtained in the Continuous Expansion Engine, or the total shaded area of the Indicator diagrams, Fig. 1, is 19 *per cent. greater* than the power obtained from the *same steam* when employed in the Ordinary Engine, or the shaded area of the diagram Fig. 2, when the expansion is carried as far as appears to be found practicable, consistently with the maintenance of a sufficient pressure of blast.

Fig. 3 shows the power obtained from the same quantity of steam in a Non-Expansive Engine when the steam is not cut off until 1 inch from the end of the 24 inch stroke; the cylinder is then about 122·9 sq. in. area (or about 12½ inches diameter), containing the same quantity of steam (2827 cub. in., at 92lbs. per in.) in 23 inches of the stroke, where it is cut off at A, the dotted line AB being the same length as in the previous diagrams.

The back pressure G is taken at the same, 5lbs. per inch, as in the first case.

The average positive pressure throughout the stroke	=	97·0lbs.
Ditto negative ditto ditto	=	14·4lbs.
Total effective pressure . .		82·6lbs.

Total Power = 122·9 in. area X 82·9lbs. per inch . = 10,151.

Then 10,151 : 22,333 : 100 : 220

Therefore Gain = 120 per cent.

of the Continuous Expansion Engine compared to a Non-Expansive Engine.

In the Continuous Expansion Engine, although the second cylinder is three times the contents of the first cylinder, the average pressure is about one-third, being 25·9lbs. compared to 73·4lbs., so that the total propelling power of each of the cylinders is very nearly equal, as in an ordinary engine, and no practical objection is occasioned.

The application of the principle to *Stationary Engines* was described in the former paper, and it was shown to be a means of carrying the expansive principle to a greater extent than is practicable in the present engines, thereby proving an important source of economy, because of the great uniformity in the combined moving power of the two cylinders as exerted upon the crank shaft in a rotary direction, on account of the cranks being at right angles, and the continuous expansion of the steam in the two cylinders; but in ordinary engines the expansion could not be carried so far, where uniformity of motion was requisite, as in driving machinery, because of the great irregularity in the rotary power that was produced when the expansion was carried far.

The comparative effects were shown by a series of diagrams, of the variations in the total amount of moving power, or labouring force, exerted in the direction of the rotary motion of the crank, in the Continuous Expansion Engine, in Woolf's Double-Cylinder Engine, and in the Cornish Engine, taking the steam in each case to be admitted at 50lbs. per inch above the atmosphere, and expanded down to the lowest useful pressure before it is condensed. The following comparative results were obtained:—

	Continuous Expansion Engine.		Woolf's Engine.		Cornish Engine.
Average amount of irregularity in moving power, throughout each stroke . . .	100	—	114	—	130
Extreme irregularity during the stroke . .	100	—	135	—	234
Comparative amount of work done by the same steam or fuel.	100	—	109	—	111

The general results of these comparisons being, that the *Cornish Engine is* 11 *per cent.*, and *Woolf's Engine is* 9 *per cent more economical* in expenditure of fuel than the *Continuous Expansion Engine*, when the expansion of the steam is carried to the *extreme limit* in each case; but that this economy cannot be obtained practically in those two engines, on account of the great irregularly in their moving power,—the *average irregularity* being in the *Cornish Engine* 30 *per cent.*, and in *Woolf's Engine* 14 *per cent. greater* than in the Continuous Expansion Engine; and the *extreme irregularity* being 134 *and* 35 *per cent.* respectively *greater*.

Consequently it appears that, although the expansion of the steam cannot be *theoretically* carried to so great an extent in the Continuous Expansion Engine as in the other two engines;—yet from the moving power being so much more uniform throughout the stroke, the expansion can be carried *practically* to a considerably greater extent; and a greater amount of economy may be practically obtained within the same *limit of uniformity* in the moving power.

The comparison between the Continuous Expansion Engine and an ordinary Non-Expansive Condensing Engine, in which the steam exerts a uniform pressure upon the piston, from the commencement to the end of the stroke, shows that the variation in the development of moving power throughout one revolution, is in the former case only 43 *per cent.*, and in the latter, 62 *per cent.*, extreme variation from the average power.

The relative economy of the two Engines, or the amount of duty obtained from the expenditure of the same quantity of fuel in each case is as 100 to 38; so that the Continuous Expansion Engine does the same work as the Non-Expansive Engine, with a more uniform moving power, and with 62 per cent. less fuel.

The Chairman observed, that the subject of the paper was interesting and important, and it was well deserving of a thorough

investigation. He enquired whether any indicator cards had been taken from the engines that were altered, to show the actual results?

Mr. SAMUEL replied, that the trials made were incomplete, and he had not had an opportunity of taking indicator diagrams from the engines, nor of carrying out the trials sufficiently to obtain comprehensive results suitable for laying before the Institution. One of the engines tried was a Goods Engine of the largest size, on the Eastern Counties Railway; the valves only were altered, and the second cylinder was not enlarged. It was only a temporary experiment, which of course caused a reduction in the extreme power that the engine could exert, and the object was more particularly to see how the principle could be best carried out in practice, and whether the proposed reduction in the blast could be effected; the result was a saving of 12 lbs. of coke per mile in consumption.

The CHAIRMAN remarked, that the steam was only supplied to one cylinder instead of two, and therefore so much less consumption of steam would take place.

Mr. SAMUEL explained, that the engine did the same usual work during the trial as before; the engine-driver could work the engine in the ordinary manner up the inclines, by shutting the communication between the two cylinders, or the engine could not probably have taken the load through the trip, but he might be using more steam than usual in the one cylinder by keeping the regulator more open.

Mr. E. JONES thought the proposed plan deserved having careful experiments tried: the diagrams shown were theoretical, and might mislead in the practical results, and he could not say how far they would agree with actual indicator diagrams, and he hoped a full trial would be made of the engine.

The CHAIRMAN considered it very desirable that the principle should be fairly tried; it seemed a good idea, and well worth being thoroughly worked out.

Mr. MCCONNELL observed, that he had doubts whether an

engine at considerable speed, using much steam, would get a sufficient blast if altered in the proposed manner, and would not require the blast-pipe to be reduced, involving a loss of power from that cause.

Mr. SAMUEL replied, that in the two engines that had been tried no difficulty appeared in making steam, and they were not found short of steam. Goods engines working at slow speed might perhaps be found the most useful cases for applying the principle. The other engine that had been tried was a passenger engine, in which the second cylinder was made double the area of the first; and it was never found short of steam, though running an express train of considerable weight. The results of the experiments as to economy were interfered with by a defect in the construction of the valves, which were tried with india-rubber packing at the back, as equilibrium valves, and proved leaky in working; and there was not an opportunity of carrying out the experiment further with valves of the ordinary kind, so that no sufficient results were obtained as to consumption, though as long as the valves remained in order the engine contrasted favourably in consumption with other engines of the same class and work. The only definite result obtained was with respect to the sufficiency of the blast, which proved quite satisfactory during the regular passenger train work of about a month.

Mr. McCONNELL thought there would be an advantage in the relative consumption of fuel, from the engine employing less steam with the same boiler, as he considered it was an important source of economy of fuel to increase the heating surface in proportion to the consumption of the cylinders, particularly in the large goods engines.

The CHAIRMAN observed, there was some uncertainty from the form of the experiment whether the economy observed was due to an improved mode of employing the steam, or was caused by not over-working the boiler; if less work was performed by the engine, then less steam was wanted from the boiler in the

same time, and the smaller quantity of steam would be generated more economically from the same firegrate and heating surface.

Mr. McConnell remarked, that great care would be required in setting the valves, to insure the proper action of the steam in the two cylinders; and it would be more important than in the case of the ordinary slide-valves, for the valve-gearing to be kept in perfect adjustment.

Mr. D. K. Clark (of Edinburgh) observed, in reference to the correctness of the conclusions to be drawn from the artificial indicator diagrams that were exhibited, that although they were artificial, they were founded on actual diagrams taken from locomotive engines, and therefore legitimate conclusions could be derived from them, and he considered they might be relied upon. The back pressure in the second cylinder, where there was no blast, had been taken in the diagram at only half-pound per inch, and would, of course, require to be matter of experiment to prove it positively; but he had observed the back pressure as low in locomotives where the valves and ports were properly adjusted; and in the diagram, taken from the Great Britain engine, at fifty-five miles per hour (which was before the Meeting), the back pressure was less than half-pound, with a blast pipe, when the steam was cut off at one-third of the stroke.

It had been assumed in the paper, that the steam could not be cut off in practice at less than one-third of the stroke, on account of the blast, but he had found it cut off at only one-fifth of the stroke in engines on the Caledonian Railway, and even less: still they worked well and appeared to make steam enough; but then it was certainly down the heavy inclines where the consumption of steam was small.

The Chairman said there was one novel circumstance in the arrangement of the proposed engine, which did not appear correct in theory: in all the previous double-cylinder engines, the first piston was allowed to complete its stroke before the steam was expanded into the second cylinder, but in this engine

the steam is passed into the second cylinder at the middle of the stroke of the first piston, thereby taking the steam away at the very moment that it is most efficient in the small cylinder.

Mr. SAMUEL explained, that at the half stroke of the first piston, the second piston was at its dead point, and began to move very slowly when the communication was opened between the two cylinders, and consequently took very little steam whilst the first piston moved through the greater portion of its remaining stroke; but then, as the first piston was getting less effective and approached its dead point, the second piston came gradually into full action, making a *continuous* expansive action, which was the peculiar feature of this engine, instead of the *intermittent* expansion of the other double-cylinder engines. This was borne out by the diagram, (Fig. 1,) showing a nearly continuous line of expansion (D F H) from beginning to end of the stroke; and the great uniformity in the total moving power of the two cylinders was shown in the former diagram, (Plate 53.)

Mr. SLATE wished some complete experiments should be made on the practical effect of expansion; he was doubtful whether so much of the theoretical advantage could be obtained in practice as had been supposed. In the present engine he could not understand the advantage of employing part of the steam at a lower pressure in a larger cylinder, as he thought that would cause the constant resistance of the atmosphere to be more seriously felt. If the strain were employed at the full pressure, say 90lbs., in the small cylinder alone, the atmospheric resistance would only cause a deduction of one-seventh of the whole power; but if the strain were only at about 30lbs. pressure in the large cylinder, this deduction for the atmospheric resistance would be increased to one-third of the power. Therefore it appeared to him most advantageous to employ the steam only in the small cylinder, to diminish the proportion of atmospheric resistance as much as possible. He thought the diagrams given, though borne out by the results of calculation, could not

be argued from like actual indicator diagrams taken from the engine, and it was very desirable for those to be obtained.

Mr. SAMUEL said he had given the best information that he was able to furnish at present respecting the engine, and wished he could have supplied more practical results. He fully agreed on the importance of a thorough practical trial, and hoped that he had brought the importance of the subject sufficiently before the members to induce such of them as had the opportunity to give it a complete trial.

The CHAIRMAN remarked, that the pressure of the steam during expansion would be affected by the condensation that always took place to a considerable extent in the cylinder, and the expansion curve in the theoretical diagrams would consequently require practical correction for the condensation and temperature. There appeared to be always some condensation produced when steam was expanded.

Mr. COWPER thought the expansion curve could be practically laid down from Pambour's experiments, as the actual deviation in practice from the theoretical rate of expansion was very little. He thought there would not be found to be any loss by condensation in a well-protected cylinder ; he had not found any condensation to take place in the experiments that he had tried on expansion.

The CHAIRMAN said he had always found a condensation take place in expanding steam, and he considered that the heat in steam was not sufficient to maintain all the steam in a gaseous state during expansion ; and a portion of it was consequently condensed.

A vote of thanks was then passed to Mr. Samuel for his communication.

The following paper, by Mr. John Wilson, of Bridgewater Works, St. Helen's, was then read:—

ON A NEW MODE OF MEASURING HIGH TEMPERATURES.

Several methods have been proposed for the measurement of temperatures beyond the range of the Mercurial Thermometer.

Wedgwood's Pyrometer was founded on the property which *clay* possesses of contracting at high temperatures. This effect, which in the first instance is due to the dissipation of the water, but afterwards to the partial vitrification occurring, which tends to bring the particles of clay into nearer proximity—may in some measure be regarded as an indication of the temperature which occasioned the contraction.

The apparatus consisted of a metallic groove, 24 inches long, the sides of which converged, being half-an-inch wide above and three tenths below. The clay was made up into little cylinders or truncated cones, which fitted the commencement of the groove after having been heated to redness; and their subsequent contraction by heat was determined by allowing them to slide from the top of the groove downwards till they arrived at a part of it through which they could not pass. Wedgwood divided the whole length of the groove into 240 degrees, each of which he supposed equal to 130° of Fahrenheit, and he fixed the *zero* of his scale at the 1077th degree of Fahrenheit's Thermometer.

"Wedgwood's Pyrometer is no longer employed by scientific men, because its indications cannot be relied on. Every observation requires a separate piece of clay, and the experimenter is never sure that the contraction of the second piece from the same heat will be exactly similar to that of the first, especially as it is difficult to procure specimens of the earth the composition of which is in every respect the same. Hence also the different results obtained by different observers; Guyton de Morveau making each degree to correspond to $62\frac{1}{2}$° of Fahrenheit, instead of 130° as stated by Wedgwood."—*(Turner's Chemistry.)*

Daniell's Pyrometer.—In the Pyrometer invented by the late

Professor Daniell, the temperature is measured by the expansion of an *iron* bar enclosed in a case. This case consists of a bar of black-lead earthenware, in which is drilled a hole, $\frac{3}{10}$ths of an inch in diameter, and $7\frac{1}{2}$ inches deep. Into this hole a cylindrical bar of platinum or soft iron, of nearly the same diameter, and $6\frac{1}{2}$ inches long, is introduced so as to rest against the solid end of the hole: and upon the outer or free end of the metallic bar rests a cylindrical piece of porcelain called the *index*, $1\frac{1}{2}$ inches long, which is kept firmly fixed in its place by a strap of platinum and a little wedge of earthenware. The object of this arrangement is, that when the instrument is heated, the metal, expanding at each temperature more than the earthenware case, presses forward the index, which, in consequence of the strap and wedge, remains in the place to which it had been forced when the instrument is removed from the fire and cooled. There is a *scale*, afterwards attached, for measuring the precise extent to which the index has been pushed forward by the metallic bar; and it thus indicates the apparent elongation of the bar, that is, the difference between its elongation and that of the black-lead case which contains it. "For its indications to be correct, (namely, that equal dilatations should indicate equal increments of heat), it is necessary that the bar and the case should expand uniformly, or both vary at the same rate. But as regards the black-lead case, its total expansion is so very small that any want of uniformity at the intermediate points cannot be detected. As for the expansions of the metallic bar, these are not exactly uniform, but still they afford a good practical index of the relative intensity of different fires, and would be an exact measure, if the precise rate of expansion could be determined."—(*Turner's Chemistry.*)

Air Pyrometer.—In some cases the measurement of high temperatures has been attempted by means of a hollow sphere of platinum, fitted with an escape tube; then the hotter the fire to which the platinum vessel is exposed, the greater is the quantity of *air* driven out of it; and this is received over water and measured. In cases where this instrument can be conveniently applied, it is capable of yielding very accurate results. (See experiments of Pouillet, tome 1, p. 351, in *Elemens de Physique et de Météorologie.*)

New Pyrometer.—The following is the method employed by the author of the present paper to measure high temperatures. Take a given weight of *platinum*, and expose it for a few minutes to the fire the temperature of which is to be measured, and then plunge it into a vessel containing *water* of a determined weight and temperature, and after the heat has been communicated to the water by the heated platinum, mark the temperature which the water has attained: and from this is estimated the temperature to which the platinum had been subjected. Thus, if the piece of platinum employed be 1000 grains, and the water into which it is plunged be 2000 grains, and its temperature 60°, should the heated platinum when dropped into the water raise its temperature to 90°, then 90°—60=30°; which, multiplied by 2, (because the water is twice the weight of the platinum,) gives 60°, that an equal weight of water would have been raised. Again; should the water in another case gain 40°, then 40° X 2 = 80°, denotes the temperature as measured by the pyrometer. To convert the degrees of this instrument into degrees of Fahrenheit, we must multiply by 31·25, or 31¼. Thus, 80° X 31¼, would give 2500° of Fahrenheit. And 60° X 31¼ = 1875°.

The multiplier 31·25 is the number expressing the *specific heat* of water as compared with that of platinum, the latter being regarded as 1.

In order to obtain very accurate results by this method, precautions similar to those required in determining the specific heat of bodies must be taken; that is, it is necessary to guard against the dissipation of heat by conduction and radiation. The apparatus used by the author is shown in Figs. 2 and 3, Plate 55, and consists of a polished tinned iron vessel, of a cylindrical form, 3 inches deep and 2 inches in diameter; this is placed within a concentric cylinder, separated from the enclosed vessel about ¼ inch. By this means there is but little heat lost during the experiment, either by radiation or conduction.

At the commencement of the experiments, the author imagined it would be necessary to employ a considerable proportion of water, and therefore took twenty-five times the weight of the platinum; but he found that the temperature gained by the water, even in

cases of very high heats, did not exceed 4° or 5°, and an error of 1°, when converted into degrees of Fahrenheit, amounted to 400°. To obtain results within much narrower limits of error, it became obvious, a much smaller proportion of water should be employed; and ultimately it was found that *double* the weight of the platinum was in all cases sufficient.

There is no appreciable loss of heat from the evaporation of steam when the hot platinum is plunged into the water;—there is probably no actual contact with the water until the platinum is fairly at the bottom of the water. It is in fact the converse of dropping water on a plate of platinum or iron *strongly* heated, in which case the water, instead of being suddenly dissipated as steam, assumes the spheroidal form, and runs about over the plate without coming in contact with the heated surface. It is only when the temperature of the metal becomes much reduced that the water is rapidly converted into vapour.

But whatever may be thought of this theory of contact, the fact is certain, that there is no necessity to increase the depth of the vessel of water to guard against the loss of heat by evaporation, or the escape of any bubbles of steam.

In ascertaining temperatures by this Pyrometer, a correction has to be made for the portion of the total heat that is absorbed by

1st, the mercury of the thermometer in the water;
2nd, the glass bulb and stem of the thermometer;
3rd, the iron vessel containing the water;
4th, the heat retained by the piece of platinum.

The portion of the total heat that is absorbed by these several bodies, compared to the portion received by the water, will be in proportion to their several weights, and the specific heat of each compared with water.

Mercury . .	200	grains	X $\frac{1}{30}$th	specific heat =	7	equivalent grains of water.
Glass . . .	35	,,	X $\frac{1}{6}$th	,,	6	,,
Iron	658	,,	X $\frac{1}{9}$th	,,	73	,,
Platinum .	1000	,,	X $\frac{1}{32}$nd	,,	31	,,
				Total . . .	117	

Therefore the effect of these bodies is equivalent to the addition of 117 grains to the 2000 grains of water, or $\frac{1}{17}$th has to be added as a correction to all the temperatures obtained by this instrument; or in other words, the multiplier must be increased from 31½ to 33 in this instrument, and in all similar ones where the weights of the mercury and glass of the thermometer, and of the iron vessel, are the same as stated above.

The following are some of the results obtained by this new Pyrometer.

In the experiments to which they refer, the melting points were ascertained by placing about two ounces of the metal in a cupel placed by the side of another cupel containing the piece of platinum;—the moment that the metal became fluid, the platinum was withdrawn, and the temperature measured as before described. It is necessary to avoid contact between the platinum and the melted body, for in some cases an alloy would be formed, and in others a portion of the melted substance would adhere to the platinum and affect the results; the closest proximity is requisite, but *contact* must be avoided. In lifting the piece of platinum, a pair of tongs is employed *heated to redness*, to prevent any abstraction of heat during the momentary contact.

TEMPERATURES OF MELTING POINTS IN DEGREES OF FAHRENHEIT.

	WILSON, With New Pyrometer.	POUILLET, With Air Pyrometer.	DANIELL, With Iron Pyrometer.
Silver	1890°	1832°	1873°
Copper	2220°	——	1996°
Grey Cast Iron	2320°	2210°	2780°
Copper-smelting Furnace	3128°	——	——
Crown Glass	2244°	——	——
Flint Glass	2145°	——	——
Copper Slag	2046°	——	——

As the piece of *platinum* is the most expensive part of the apparatus, it is proposed that for practical purposes generally, a small piece of *baked Stourbridge clay* be substituted for the platinum;

and the author has found by experiment, that a piece of Stourbridge clay, 200 grains in weight, when heated to the melting point of *silver*, and then plunged into the tinned vessel containing 2000 grains of water, raises the temperature of the water 41°.

Now if 1890° Fahrenheit, (the melting point of silver found before,) be divided by 41, we obtain 46° as the number corresponding to 1° of this pyrometer; and 46 will therefore be the correct multiplier, and no corrections are required for any heat abstracted by the thermometer, the tinned vessel, or the piece of clay.

The temperature of all sorts of furnaces and flues of steam-engines, &c., may be readily ascertained by means of the piece of Stourbridge clay.

Mr. WILSON exhibited his new instrument, and showed the mode of using it.

The CHAIRMAN expressed the interest he felt in this new pyrometer that had been brought before the meeting, and considered it an ingenious and efficient instrument. He remembered having a conversation with the late Professor Daniell on the subject of his pyrometer, and expressing a doubt of the nearness of the approximation in the results obtained from that instrument; in fact, such delicate manipulation was required in using it, that it was scarcely available except in the hands of the inventor himself. But Mr. Wilson's instrument was so extremely simple in the construction and practical application, that an accurate measure of the quantity of heat could be relied upon, with ordinary care in the employment of the instrument.

It might be theoretically considered, that *quantity* of heat was a different point from *intensity* of heat, as in the case of voltaic electricity, the difference between quantity and intensity was known to be so strongly marked in the different effects produced; and this pyrometer, although measuring correctly the relative quantity of heat required to melt different bodies, might give far from a correct measure of the relative intensity

of different fires. However, the same theoretical question applied of course to the ordinary mercurial thermometer, which was also the standard of measure in this pyrometer, and to all thermometers which measured the degree of heat by the relative expansion of any body by heat, whether mercury, iron, or air. He inquired whether Mr. Wilson had tried the temperatures of any furnaces and flues with his pyrometer?

Mr. Wilson replied that he had not had an opportunity at present of making experiments on the temperature of furnaces, &c., but hoped to do so shortly. He proposed to employ the pieces of Stourbridge clay for this purpose, and to carry the piece of clay in a small bowl or hollow at the end of an iron rod, which could be readily introduced into the flue through a small hole in the side, and after being left there as long as required to insure the full temperature being attained, the iron rod could be withdrawn and the piece of clay dropped instantly into the vessel of water, without being touched by any other body.

Mr. Clift enquired whether the pieces of clay could be used more than once, on account of cracking when plunged into the water: and whether there was not a difficulty in obtaining them sufficiently uniform in composition and in specific heat to afford a correct measure?

Mr. Wilson replied that he had not found any difficulty in using the pieces of clay, and had used the same piece as many as eight time without any change, and he expected it would do for a hundred times. It was only requisite to obtain ordinary pure clay, and to have the pieces well fired. The pieces should not exceed the size shown, half-an-inch in thickness, to ensure the clay being uniformly heated throughout, as it was so slow a conductor of heat.

The Chairman suggested that, as a check upon its accuracy, the pyrometer should be tried with lead and some other metals of which the melting points were already accurately ascertained, being within the range of the mercurial thermometer.

Mr. Wilson said he had tried it with zinc, but not with

lead. He remarked, that any body might be employed for the construction of a pyrometer on this principle, by measuring its relative weight compared with the water, provided that its specific heat was correctly known. But it was necessary to observe that in measuring the melting point of bodies, the temperature must be taken just before melting takes place, because at the moment of liquifaction a certain quantity of latent heat was absorbed, as in the case of ice being melted into water; and beyond that point the temperature of the melted metal might rise considerably, and make the observation incorrect. In the case of the melting point of silver, he had found an error of 400° was caused when this was not attended to.

The results obtained by this pyrometer could not be regarded as *absolutely* correct, since the specific heat of platinum is assumed as constant at all temperatures, which is not strictly true. Nevertheless, these results are quite as near approximations to perfect accuracy as those given by the common mercurial thermometer, and all other instruments of the kind founded on the principle of expansion; for the variations in the rate of dilation at different temperatures are quite as great as the variations in the specific heat of a body.

The CHAIRMAN proposed a vote of thanks to Mr. Wilson, for his interesting and valuable communication, which was passed.

The following paper, by Mr. Daniel K. Clark, of Edinburgh, was then read:—

ON THE EXPANSIVE WORKING OF STEAM IN LOCOMOTIVES.

The opinions as well as the practice of Engineers on the working of Steam expansively in Steam engines, have been, and still are at variance. Though many are disposed to grant that

there may be under certain conditions a sensible economy of steam when worked expansively, they have no durable faith in the principle, and consequently in their practice they do not concern themselves with the provisions which are essential to its success. In locomotives this want of confidence is conspicuous, for in many of them, as will be shown, the most obvious conditions of success in the employment of steam expansively, are overlooked in their design and arrangement. The opinion has been recently placed on record, in reference to expansive working in locomotives, that "it seems very doubtful in theory, and the results of practice would seem to confirm this view, whether any real advantage is gained by the so-called expansive working." In coming to this conclusion, however, it was assumed that the steam has a comparatively low average pressure in the cylinder at high speeds. In such circumstances the benefit would be proportionally limited; but this is a very partial view of the question, as the reduction of pressure at high speeds is merely incidental to defective proportions.

This leads to the first grand defect in the general design of locomotives—the adoption of a low standard of steam pressure in the boiler. The more expansively the steam is worked in a given cylinder, the less is the effective mean pressure on the piston, and the less is the work done by the engine. It therefore happens in many cases that the liberty of working expansively is limited by the necessity for a sufficiency of power to do the work required; and that in the performance of ordinary work, the demand for power is such as to require the steam to be admitted to the cylinder during one half to two thirds of the stroke. Besides, the habitual use of high-pressed steam in the cylinder reduces the relative importance of the atmosphere as a neutralizer of power.

Secondly, even were the power sufficiently great to permit of highly expansive working, the cylinders are in many engines so imperfectly protected, as partially to condense the steam within them. Moreover the proportion of steam condensed increases with the degree of expansion, and so serious is the destruction of power from this cause, that even were the pressure sufficiently great to permit of highly expansive working, the benefit of expansion, if it be attempted by cutting-off earlier than from one half to one third

of the stroke, is neutralized by the greater condensation of the steam thereby incurred.

The object of this paper is to show at what rate in practice the efficiency of steam is increased by expansive working in Locomotives with the best existing arrangements of cylinders, valves, and valve gear, and to point out the conditions on which expansive action may be most successfully carried out.

I.—*Of the action and capabilities of the Link-motion.*—The action of the valves in the "distribution" of the steam (a term borrowed from the French) is regulated by three elements, the lap, the lead, and the travel. When these are given, the point of the stroke of the piston at which the steam is admitted to the cylinder, cut-off, exhausted, and compressed or shut up, are all deduceable by model, by diagram, or by calculation. This can be done, whether the valve derives its motion from a single eccentric, or from a link-motion, as the motion of the valve is virtually the same in both cases. The way in which the valve is caused to cut-off or suppress the steam earlier by the link motion, is by *shortening the travel of the valve;* this is accomplished by means of the reversing gear, in such a manner that whatever be the reduction of travel communicated to the valve, the lead is always at least the same as in full gear, and with the shifting link is rather increased. In shortening the travel, not only is the steam cut-off at an earlier point of the stroke; it is also exhausted earlier, and admitted earlier, and the exhaust port is closed earlier during the return stroke upon the exhaust steam. Thus, by shortening the travel, every thing affecting the distribution is done earlier in the course of the steam and return strokes. This conclusion is very well illustrated by the excellent diagrams of the valve motion of the Atlas Goods Engine, with which the members of the Institution are familiar.

In his experiments on the action of steam, the writer employed Mc Naught's Indicator, which he applied to the front end of one of the cylinders of the engine, and received the alternate motion for the paper-cylinder from the end of the piston rod, through an intermediate lever suspended from the engine frame. To test the actual state of the valve-gear of each engine at the time of the

experiment, so far as it affected the distribution, Indicator diagrams were obtained from the cylinder at very low speeds, under each notch of the sector of the reversing gear. The diagrams so obtained, of which some examples are given in Figs. 1, 2, and 3, Plates 55 and 56, are angular and sharply defined, and they show with precision at what points of the stroke the changes of the distribution take place For instance, in the diagram, Fig. 1, Plate 55, (from the Caledonian Railway Engine, No. 13, fitted with shifting links, taken under full-gear, in the first notch of the sector, and marked No. 1); the opening of the port for the admission of steam commences at the point A, about $\frac{3}{16}$ths-inch before the beginning of the steam stroke, when the line starts upwards to the regular steam level at B, in time to commence the steam stroke at full pressure. From B to C, the steam is shown to be admitted to the cylinder at a uniform pressure of 38 lbs. At C, it is cut-off, or suppressed, and while the piston moves from C to D, the enclosed steam expands behind it at a regularly decreasing pressure, shown by the curve C D. At D, the steam is exhausted, and the pressure quickly declines till the end of the steam stroke E. During the return or exhaust stroke, the steam continues to exhaust into the atmosphere, and the atmospheric line E F is described. When the piston arrives at F, the exhaust steam is denied any further egress, and the piston continuing in motion, it compresses the steam against the end of the cylinder, and raises the pressure as indicated by the line F A, until at A steam is admitted from the steam-chest for the next steam stroke. The *portions* of the double stroke described by the piston during this succession of changes or events, traced for one face of the piston, are distinguished by the writer as the *periods* of the distribution, and the *points* of the stroke at which the changes occur, as the *points* of the distribution. These are further distinguished as follow:—

A is the *point of admission;*

C is the *point of cutting-off, or suppression;*

D is the *point of exhaust, or release;*

F is the *point of compression;* also the portion of the stroke described while the line AB is traced, is the *period of pre-admission;*

The portion of the stroke BC is the *period of admission ;*

The portion between C and D is the *period of expansion ;*

The portion between D and E is the *period of exhaust* during the steam stroke ;

The portion EF is the *period of exhaust* during the return stroke ;

The portion between F and A is strictly the *period of compression ;* but the period of *pre-admission* is generally added to it, and thus the compression usually signifies the whole distance of the point F from the end of the return stroke.

These definitions apply to diagrams taken from every notch of the sector, as it will be seen from the diagrams Nos. 2, 3, 4, Fig. 1, from the same engine, that however varied in form, they have all the parts of the diagram No. 1, for full-gear.

The following Table, No. 1, contains the positions of the points of the distribution of No. 13, C.R. Engine, for every notch of the sector, measured from the beginning of the steam stroke.

TABLE No. 1.—*The Distribution for No.* 13 *C.R. Engine.*

Stroke	20	inches
Lead in full-gear	$\frac{5}{16}$	,,
Ditto in mid-gear	$\frac{9}{16}$	,,
Lap	$1\frac{1}{4}$	,,
Travel	$4\frac{1}{2}$	,,

No. of Notch.	Points of the Distribution.							
	Cutting-off.		Exhaust.		Compression.		Admission.	
	Inches of Stroke.	Pr. cent. of Stroke.	Inches of Stroke.	Pr. cent. of Stroke.	Inches of Stroke.	Pr. cent. of Stroke.	Inches of Stroke.	Pr. cent. of Stroke.
No. 1, full-gear forward . .	$12\frac{1}{2}$	63	$17\frac{1}{4}$	86	$2\frac{5}{8}$	13	$\frac{3}{16}$	1
No. 2	$9\frac{3}{4}$	49	$16\frac{1}{4}$	82	$3\frac{3}{4}$	19	$\frac{5}{16}$	2
No. 3	$6\frac{5}{8}$	33	$14\frac{1}{4}$	72	$6\frac{1}{4}$	32	1	5
No. 4, mid-gear forward . .	$3\frac{1}{8}$	155	$10\frac{3}{4}$	54	$9\frac{1}{2}$	48	$2\frac{1}{8}$	11

1st.—It is obvious from this table, in conjunction with the diagrams, that the sooner the steam is cut-off, the sooner it is exhausted, the sooner the port is closed for exhaustion, and the sooner the port is opened for the admission of steam.

2nd.—That though every change is made earlier—as measured in parts of the stroke—there is less difference in the position of the points of exhaust, compression, and admission, than in that of the cutting off. Consequently, the shorter the admission, the longer is the expansion, as the exhaust point does not recede so much as the point of cutting off.

3rd.—That by the shifting link-motion, the steam may be cut off at from $\frac{1}{8}$th to $\frac{1}{7}$th of the stroke.

4th.—That though the exhaust takes place earlier for every increase of expansion, it does not in any case take place within the first half of the stroke. For mid-gear it occurs in fact at 54 per cent. of the stroke; and the steam is expanded into $3\frac{1}{2}$ times the length of stroke at which it is cut off.

5th.—That the period of compression, increasing as the admission is reduced, amount to about one-half stroke in mid-gear.

6th.—That the pre-admission of the steam, not above 1 per cent. of the stroke in full gear, reaches about 10 per cent. in mid-gear.

*

These results are for an ordinary *shifting link-motion*, in every modification of which the lead increases with the degree of expansion, and in which the lead in this case rises from $\frac{5}{16}$ths to $\frac{9}{16}$ths inch in mid-gear. Whereas, in *stationary link-motions*, having the links suspended directly from a fixed point, the lead is constant for all degrees of expansion; and if in these the lead be set at $\frac{1}{4}$th to $\frac{5}{16}$ths inch constant, we should be able to cut off at even 10 to 12 per cent. of the stroke, or at $\frac{1}{10}$th to $\frac{1}{8}$th of the stroke. For example, in the diagram from No. 125, C.R. Engine, in Fig. 3, Plate 56, (lap $1\frac{1}{4}$ inch, lead $\frac{1}{4}$ inch,) the steam is shown in No. 5 diagram to be cut-off at $3\frac{1}{2}$ out of 24 inches stroke, or at $\frac{1}{7}$th from the front end of the cylinder. Now in this engine, as the valve-gearing was slightly out of balance, the steam was cut off 1 inch earlier for the back stroke in mid-gear, that is, at $2\frac{1}{2}$ inches; and the mean of the two, or 3 inches, is the mean admission in mid-gear, or $\frac{1}{8}$th of the stroke.

It has been thought necessary to go into these preliminary explanations, to show that *the link-motion is capable of cutting off steam as early* in the course of the stroke *as can ever be advisable* in practice.

It has been seen that the earlier the steam is cut-off, the *earlier also it is exhausted*; until in mid-gear it may be released at half-stroke. This has been deemed a serious objection to the use of link-motions for high expansion, as it is supposed to lead to a serious loss of expansive action, by exhausting prematurely. This loss is, however, a mere trifle in practice. The escape of the steam is by no means instantaneous, as the slow diagrams in Figs. 1, 2, and 3, very clearly prove. Thus, in the diagram No. 1, Fig. 1, from No. 13, C.R. Engine, the exhaust-line DE shows that nearly all the period of exhaust for the steam stroke is employed for the complete evacuation of the steam. And if this be the case for speeds of 1 and 2 miles an hour, it is much more so for the regular working speeds of trains. To select from a very admirable series of Indicator diagrams, with copies of which the writer has been favoured by Mr. Daniel Gooch, by whom they were taken from the cylinder of the Great Britain Locomotive, on the Great Western Railway, the Figs. 4 and 5, Plate 57, contain diagrams taken at 17 and 55 miles per hour respectively, under the 1st, 3rd, and 5th notches of the sector. The following are the conditions of the valve-motion of this engine, when the diagrams were taken:—

TABLE No. 2.—*State of the Valves of the "Great Britain," G.W.R.*

Cylinder, 18 X 24 inches. Wheel, 8 feet.

Lap	$1\frac{1}{4}$ inch.
Constant lead	$\frac{3}{8}$,,
Travel in full-gear	$4\frac{3}{4}$,,
Blast orifice	$5\frac{1}{2}$,, diameter.

No. of Notch.	Position of Points of Distribution.			Period of Exhaust during the Steam-Stroke
	Cutting-off.	Exhaust.	Compression.	
	Inches of Stroke.	Inches of Stroke.	Inches of Stroke.	Inches of Stroke.
1	16	$21\frac{3}{8}$	3	$2\frac{5}{8}$
3	$11\frac{3}{4}$	$19\frac{3}{4}$	5	$4\frac{1}{4}$
5	7	$17\frac{3}{8}$	$7\frac{1}{2}$	$6\frac{5}{8}$

On the diagrams the points of cutting-off and exhaust are marked, and the steam line falls only very gradually during the period of exhaust, especially at the high speeds. The expansion-curves are shown by dotted lines A, B, C, Figs. 4 and 5, continued to the end of the stroke. These are easily calculated in terms of the relative volumes of steam, from the pressures indicated at the points of exhaust, and are such as would have been described had the exhaust been delayed till the end of the stroke. The shaded areas A, B, C, enclosed between these dotted curves, and the curves actually described, express the *power lost* by exhausting the steam *before the stroke is completed.* Averaging them for the whole stroke, they are as follows:—

Low Speeds	1st Notch,	$\frac{7}{8}$	lb.	per inch	loss.
	3rd	,,	$2\frac{1}{4}$	,,	,,	,,
	5th	,,	$3\frac{1}{8}$	,,	,,	,,
High Speeds.	1st	,,	1	,,	,,	,,
	3rd	,,	1	,,	,,	,,
	5th	,,	$\frac{3}{8}$	,,	,,	,,

The losses at high speeds are very small,—merely nominal; and curiously enough, the loss by the *earlier* exhaust of the 5th notch is actually less than that under the 1st notch. The losses are of course greater at the low speeds; but even then, in the 1st notch, which is the only notch employed at very low speeds, the loss does not amount to 1 lb. per inch. The 3rd and 5th notches are employed only at speeds much above 17 miles per hour, and the loss by them is of no practical moment.

Upon the whole, it follows that the possible *loss by the early exhaust* yielded by the link-motion is of *no importance.* On the contrary, it can be proved to be *beneficial*, as an early exhaust is at high speeds essential to a perfect exhaust during the return-stroke. It plainly appears, therefore, that with the existing arrangements of locomotives, any attempts to eke out the power on the steam-line, by prolonging the expansion materially beyond what is accomplished

by an ordinary valve and link-motion, are not only useless, but highly prejudicial.

Another objection to the link-motion is that the steam is injuriously *wiredrawn* by it when under great expansion. Hence the numerous attempts to supersede the link by the employment of a separate expansion-valve. The diagrams, Fig. 5, Plate 57, may be referred to as examples of wire-drawing by the link. They were taken nearly consecutively with one opening of the regulator; and it is clear that the steam attained fully as high a pressure in the cylinder under the 5th notch as under the 1st. The pressure falls considerably towards the point of cutting-off, but from the form of the steam-line, it is plain that very little additional steam is admitted for an inch or two before the cutting-off actually takes place. The most of the steam is admitted at the higher pressure, and in fact a partial expansion of the steam already admitted takes place for some distance before the expansion nominally begins. Thus the *wire-drawing* is, to a great extent, equivalent to an *earlier cutting-off*, and a greater degree of expansion. The whole possible loss by wire-drawing is comprised within the dotted line D, added to the diagram, which is merely an extensisn of the expansion curve, to meet the steam line, drawn horizontally to represent a free admission up to an imaginary point D of cutting-off, 5 inches from the beginning of the stroke. This shaded area D amounts exactly to a mean loss upon the whole stroke of *one pound per square inch*, by *wire-drawing*, under high expansion. For thə 1st and 3rd notch, the amount of loss by wire-drawing, must obviously be still less; and, in short, the objection of *wire-drawing by the link-motion*, when of liberal proportions, is of *no practical weight.*

Another objection to the link-motion, and apparently the most formidable one, is the large fraction of power neutralised by the *compression* of the exhaust-steam, and which increases with the degree of expansion. Compression, however, involves no loss of efficiency; for as by compression a quantity of steam is incidentally reserved and raised to a higher pressure, it gives out the power so expended

in compressing it, during the next steam-stroke, just as a compressed spring would do in the recoil. But, apart from this general argument, the actual efficiency of the steam in the cylinder, with and without compression, may be exactly estimated. The most direct method of doing so, is to find the quantities of water consumed as steam for one stroke, under the two conditions, and to compare them with the relative effective mean pressures. It will suffice to analyse, as an example, the high speed diagram, Fig. 5, Plate 57, under the 5th notch, No. 5. The volume of steam admitted is measured by the product of the area of piston, (254·47 inches), and the period of admission, plus the total clearance in the cylinder and steam-passage; the clearance being measured for simplicity in inches of stroke, we have 7 + 1·8=8·8 inches, for the total volume admitted. The pressure of the steam when cut-off is 65 lbs., for which the relative volume of water is 359. Therefore the volume of water as steam, or the water-equivalent of the steam admitted, is

$$\frac{254{\cdot}47 \times 8{\cdot}8}{359} = 6{\cdot}24 \text{ cubic inches.}$$

From this is to to be deducted the quantity of steam reserved by compression; the volume so reserved is measured by the period of compression, plus the clearance (7·5 + 1·8=9·3), and the pressure at the point of compression is 8 lbs., for which the relative volume is 1125. Then the water-equivalent of the reserved steam is—

$$\frac{254{\cdot}47 \times 9{\cdot}3}{1125} = 2{\cdot}10 \text{ cubic inches;}$$

subtracting, there remains 6·24 — 2·10=4·14 cubic inches of water as steam, actually expended for one stroke of the piston.

Were there to be no reservation of exhaust steam by foreclosing the exhaust-port, the whole area of resistance by compression would be removed, and there would be a reserve of steam of atmospheric pressure equal in volume to the clearance only. The relative volume of atmospheric steam is 1669, and the water-equivalent of the reserve, would be—

$$\frac{254{\cdot}47 \times 1{\cdot}8}{1669} = 0{\cdot}27 \text{ cubic inches:}$$

the expenditure per stroke would be 6·24 — 0·27 = 5·97 inches of water.

Now, the poitive mean pressure during the steam-stroke, as indicated, is . . . . 40·9lbs. per inch,
And the mean resistance by compression is . . 11·5lbs. „

Thus the effective mean pressure is . . . . . . 29·4lbs. „

This effective mean pressure of 29·4lbs. is maintained by a consumption of 4·14 inches of water per stroke; and it has just been found that with the compression removed, the positive mean pressure of 40·9lbs. per inch would be maintained by a consumption of 5·97 inches of water per stroke. The effective pressure created per cubic inch of water is, therefore,

In actual practice . . . . $\frac{29{\cdot}4}{4{\cdot}14} = 7{\cdot}1$lbs.

And would be by removing compression $\frac{40{\cdot}9}{5{\cdot}97} = 6{\cdot}9$lbs.

These quantities are expressions of the relative efficiency of steam employed with and without compression: they are virtually identical, and show that the resistance by compression in the cylinder, due to the action of the link-motion, does not in the slightest degree impair the efficiency of the steam.

The last objection to the use of the link, requiring notice, is that at *high speeds* considerable *back exhaust pressure* is created. The amount of this is very various, and it depends also on circumstances for which the link-motion is not responsible; such as a deficiency of inside lead, (which is regulated by the lap,) small ports, a small blast-orifice, and imperfect protection of the cylinder. It suffices on the present occasion to point to what can be done by superior arrangements, as exemplified in the diagrams, Fig. 5, Plate 57, from the "Great Britain." The cylinders of this engine are in a manner suspended in the smoke-box, and thoroughly protected; the steam-ways are very large, 13 X 2 inches, being in area about $\frac{1}{10}$th of the cylinder; the exhaust-passage is very direct; and the blast-orfice is $5\frac{1}{2}$ inches diameter, or about $\frac{1}{11}$th of the area of cylinder. As a whole, these proportions are superior to those of any other engines with which the writer is acquainted;

and the diagrams prove that the per-centages of back exhaust pressure, in terms of the positive mean pressure, at 55 miles per hour, are—

For the 1st notch	. . . . . .	$8\frac{3}{8}$ per cent.
,, 3rd ditto	. . . . . .	$5\frac{3}{4}$,,
,, 5th ditto	. . . . . .	nothing.

Better results than these should not in practice be required, for when locomotives are adapted to their work, and running at high speeds, they ought not to require an admission of steam above half-stroke. However, the area of blast-orifice rules the back exhaust-pressure; and, when the cylinder is duly proportioned to the boiler, it is quite practicable, by a few modifications in detail, still further to increase the orifice, sufficiently to banish all traces of back-pressure of exhaust at all practicable speeds.

Having noticed the prevailing *objections to the link* as a means of *variable expansive working*, and shown that there is no good ground for entertaining these objections, it remains to be shown at what rate the efficiency of steam is increased by expansive working.

II.—*Of the rate of Efficiency of Steam worked expansively in the Locomotive, by the Link-motion.*—It is customary to apply the law of expansion discovered by Boyle, and better known as Marriotte's law, to determine the work done by steam acting expansively. In the present case, this mode of inquiry would be of little service, for though steam in well-protected cylinders expands nearly according to Boyle's law, or such that the total volume by expansion varies inversely as the total pressure, yet the results are affected by other circumstances;—chiefly, the amount of clearance, wire-drawing, and back-pressure of exhaust and compression. It will be preferable to take the aggregate results of all these influences, as embodied in the model-diagrams from the "Great Britain:"—this method will ensure accurate conclusions, and will simplify the discussion. Twenty-six indicator-diagrams were obtained, at speeds varying from 15 to 56 miles per hour, of which the samples, Figs. 4 and 5, Plate 57, taken at the opposite extremes of speed, suffice to point out the general characteristics. The Table, No. 3, contains in the first nine columns an analysis of these diagrams, which requires no further explanation; the effective horse-powers, column 10, are

TABLE No. 3.—*Results from Indicator-Diagrams,*

No. of Diagram.	Speed of Engine in Miles per Hour	Indicated Steam Pressures in Cylinder, in lbs. per Square Inch.						
		Maximum Pressure during Admission	Positive Mean Pressure.	Back Pressures.				Effective Mean Pressure.
				Exhaust.	Compression.	Sum of Back Pressures.		
						Pressure.	Per Cent. of positive Steam Pressure.	
	Miles	lbs.	lbs.	lbs.	lbs.	lbs.	Per Cent.	lbs.
1	15	70	63·8	1·6	2·4	4·0	6·1	59·8
2	17	88	80·0	0·6	1·9	2·5	3·0	77·5
3	21	95	86·2	1·2	3·0	4·2	4·7	82·0
4	24	85	76·7	0·9	1·6	2·5	3·1	74·2
5	27	80	70·6	1·5	2·2	3·7	5·3	66·9
6	31	90	79·6	1·7	3·7	5·4	6·7	74·2
7	31	80	73·2	2·9	2·2	5·1	6·9	68·1
8	49	60	51·4	3·6	4.4	8·0	15·5	43·4
9	54	89	80·4	6·8	6·0	12·8	15·8	67·6
1st Notch—Means		82						68·2
10	17	88	69·9	0·0	3·8	3·8	5·4	66·1
11	18	70	55·3	0·8	4·5	5·3	9·4	50·0
12	21	92	72·3	0·0	4·2	4·2	5·7	68·1
13	26	72	57·1	0·0	4·9	4·9	8·5	52·2
14	31	79	60·3	1·2	6·0	7·2	11·9	53·1
15	32	86	64·4	0·8	4·9	5·7	8·4	58·7
16	40	76	55·7	0·4	4·7	5·1	9·1	50·6
17	51	70	49·1	2·0	6·2	8·2	16·6	40·9
18	55	84	62·0	3·6	7·6	11·2	18·0	50·8
3rd Notch—Means		80						54·5
19	17	89	53·2	0·0	9·6	9·6	18·0	43·5
20	18	70	42·1	0·5	6·6	7·1	16·7	35·0
21	21	93	56·5	0·0	6·3	6·3	11·1	50·2
22	28	74	41·8	0·4	6·2	6·6	15·7	35·2
23	31	83	46·5	0·0	7·4	7·4	15·5	39·1
24	36	80	39·0	0·0	8·5	8·5	21·1	30·5
25	50	77	34·7	0·5	8·0	8·5	24·4	26·2
26	56	90	40·9	0·0	11·5	11·5	28·1	29·4
5th Notch—Means		82						36·1
1	2	3	4	5	6	7	8	9

taken from the "Great Britain" in 1850.

Effective Horse Power Indicated.	Water Equivalents. Total admitted for One Stroke, measured from Diagram.	Water Equivalents. Reserved by Compression.	Water Equivalents. Actually expended during one steam Stroke.	Water Equivalents. Actually expended per Hour.	Water Equivalents. Actually expended per Effective Horse Power per Hour.		Coke consumed per Effective Horse Power per Hour, allowing 1 lb. for 8 lbs. water.
H. P.	Cubic ins.	Cubic ins.	Cubic ins.	Cubic feet.	Cubic ins.	lbs.	lbs.
190	13·32	1·00	12·53	89·83	817	29·5	3·69
284	15·89	0·82	15·07	124·53	758	27·4	3·42
372	16·71	1·09	15·62	159·45	741	26·8	3·35
384	15·30	0·82	14·48	168·95	760	27·5	3·44
389	13·89	0·91	12·98	170·37	757	27·4	3·42
497	15·62	1·13	14·49	218·35	759	27·4	3·42
456	14·76	1·00	13·76	207·35	786	28·4	3·55
459	10·73	1·34	9·39	223·60	842	30·4	3·80
763	15·62	1·56	14·06	369·07	836	30·2	3·77
						28·3	3·54
242	12·19	1·10	11·09	91·65	654	23·7	2·96
194	10·33	1·35	8·98	78·57	700	25·3	3·16
309	12·50	1·16	11·34	115·78	647	23·4	2·92
293	10·55	1·41	9·14	115·52	681	24·6	3·07
356	10·87	1·48	9·39	141·50	687	24·8	3·10
407	11·33	1·29	10·04	156·20	663	24·0	3·00
437	9·78	1·35	8·43	163·87	648	23·4	2·92
450	8·65	1·54	7·11	176·30	677	24·5	3·06
603	10·54	1·66	8·88	237·42	680	24·6	3·07
						24·3	3·03
159	7·90	1·85	6·05	50·00	543	19·6	2·45
136	6·59	1·76	4·83	42·26	537	19·4	2·42
228	8·20	1·42	6·78	69·21	525	18·9	2·36
213	6·87	1·68	5·19	70·64	537	20·7	2·59
262	7·29	1·59	5·70	85·89	566	20·5	2·56
237	6·08	1·85	4·23	74·02	540	19·5	2·44
263	5·52	1·76	3·76	91·39	600	21·7	2·71
353	6·24	2·10	4·14	113·20	554	20·1	2·51
						20·1	2·51
10	11	12	13	14	15	16	17

estimated in terms of the diameter and stroke of cylinder, the diameter of wheel, and the effective mean-pressures in the 9th column. The water-equivalents, columns 11, 12, and 13, are estimated from the indicated pressures and the period of the distribution for each notch, in the way already exemplified. The expenditure of steam per hour, column 14, is deduced from column 13, in terms of the speed, the cylinder, and the wheel; and, dividing that by the effective horse-power, we have the contents of column 15 in inches, and of column 16 in pounds. Column 17 contains the coke consumed per horse-power per hour, deduced for the several diagrams from the consumption of water, column 16, allowing 1lb. of coke to evaporate 8lbs. of water.

Referring to the contents of the last two columns of this table, it is obvious that the consumption of water as steam, or of coke, for a given amount of work done, becomes less the more expansively the steam is worked; and the means of the several quantities for the notches separately are as follow :—

CONSUMPTION PER HORSE-POWER PER HOUR.

For the	1st notch,	28·3 lbs.	water,	or	3·54 lbs.	coke.
„	3rd „	24·3 „	„	„	3·03 „	„
„	5th „	20·1 „	„	„	2·51 „	„

As the results under each notch vary very little, the means above stated may be adopted for all practical speeds without material error. To find from these means a formula which shall express the rate of economy by expansive working: it may be done graphically thus :—see Fig. 6, Plate 56. Draw a base-line AB, to represent the stroke of the piston; set off on this base-line the distances AE, AF, and AG, equal respectively to the periods of admission under the 1st, 3rd, and 5th notches. From the points E, F, G, draw the perpendiculars equal respectively to the pounds of water per horse-power per hour consumed under the different notches, by any convenient scale of pressure, and terminate them by points, as drawn; these points are found to range in a straight line, CD, which meets the vertical from A, at a height of 14 lbs. by the scale, and the vertical from B, at 36 lbs. The straightness of the line

CD implies that the consumption decreases uniformly with the period of admission of the steam; the difference of heights, (36—14) or 22 lbs., is the whole decrease for the whole stroke. Consequently, if 22 be multiplied by the period of admission, and divided by the length of stroke, and 14 added to the quotient, the sum will express the consumption.

Let L = the length of stroke,
S = the period of admission of steam,
and W = the consumption of water in pounds per horse-power per hour;

then $$W = 22\frac{S}{L} + 14 \qquad (1.)$$

or, at length:—

RULE I.—*To find the Consumption of Water as Steam per Horse-power per hour, for a given period of admission.* Multiply the period of admission in inches by 22, and divide by the length of stroke in inches; and add 14 to the quotient. The sum is the required consumption in pounds.

For the *Consumption of Coke*, allowing 1 lb. for the evaporation of 8 lbs. of water, divide the water, as above found, by 8; and, making C the consumption of coke, we have

$$C = 2{\cdot}75\frac{S}{L} + 1{\cdot}75 \qquad (2.)$$

or, at length:—

RULE II.—*To find the Consumption of Coke per Horse-power per hour, for a given period of admission.* Multiply the period of admission in inches by 2·75, and divide by the length of stroke in inches, and add 1·75 to the quotient. The sum is the consumption in pounds per horse-power per hour.

These rules may be employed with safety for all periods of admission between 10 and 75 per cent. of the stroke, which are the utmost limits worth regarding in the locomotive engine. They are applicable, also, for maximum pressures during admission, ranging between 60 lbs. and 120 lbs., though based on results from steam of 80 lbs. to 84 lbs. maximum pressure For extreme pressures, the results by the rule are slightly too small in the case of lower pressures, and rather greater for the higher,—these divergences being

due to the constant deduction of 15 lbs. for atmospheric resistance from the total pressure. It is presumed that engineers will not return to the error of low pressures in locomotives, and that high pressures will be cultivated. For pressures above 80 lbs., the rules are perfectly safe, as they err rather by excess on the safe side. The relative advantage of higher pressures, in respect of the constant loss by the atmosphere, progresses but slowly for pressures above 80 lbs. At this pressure, or 95 lbs. total, the atmosphere deducts $\frac{1}{6{\cdot}33}$rd; and at 100 lbs., the loss is $\frac{1}{7{\cdot}66}$th. The difference of these fractions is $\frac{1}{36}$th, which is all the economy on account of atmospheric resistance by the use of 100 lbs. steam, compared with the work done at 80 lbs. For 120 lbs., the economy is $\frac{1}{21}$th, and for 150 lbs., it is $\frac{1}{15}$th, with respect to 80 lbs. The chief advantage, therefore, of the highest pressure, is in the liberty of working more expansively, while developing power at a given rate.

The following Table, No. 4, shows in the second column the consumption of steam worked expansively per horse-power per hour, due, by Rule I, to the periods of admission named in the 1st column, and expressed in per cent. of the stroke. The inverse ratios of those quantities of steam are entered in col. 3, the consumption for 100 per cent. being expressed by 1. Thus the actual relative efficiency of steam is found for various admissions. The 4th column contains the theoretical maximum relative efficiency of steam, expanding to the end of the stroke, according to the law of Boyle, with a perfect vacuum behind the piston, and without clearance, back-pressure, or compression; extracted from the ordinary tables on the subject. In col. 5, are given the relative amounts of work done by steam, under the admissions named in col. 1, being directly as the effective mean pressures in the cylinder, which are found by a rule to be afterwards given.

TABLE No. 4.—*Efficiency of Steam by Expansion in the Cylinder of the Locomotive, in Actual Practice.*

For Maximum Pressures during admission of 60 lbs. to 120 lbs.

Periods of Admission in parts of Stroke	Water as Steam consumed in Pounds per H. P. per Hour	Relative Efficiency of Steam in Actual Practice	Possible Maximum Efficiency	Relative Work done by Steam of the same Maximum Pressure in the Cylinder.
Per cent	lbs.			
10	16·2	2·22	3·30	15
12·5	16·7	2·15	3·08	20
15	17·3	2·08	2·90	24
17·5	17·8	2·02	2·73	28
20	18·4	1·96	2·60	32
25	19·5	1·85	2·39	40
30	20·6	1·75	2·20	46
35	21·7	1·66	2·05	52
40	22·8	1·58	1·92	57
45	23·9	1·50	1·80	62
50	25·0	1·44	1·69	67
55	26·1	1·38	1·60	72
60	27·2	1·32	1·51	77
65	28·3	1·27	1·43	81
70	29·4	1·23	1·35	85
75	30·5	1·18	1·28	89
100	36·0	1·00	1·00	100

From this table it appears that, in actual practice, the relative efficiency of steam when cut-off at $\frac{1}{10}$th of the stroke, is $2\frac{1}{4}$ times greater than when not cut-off until the end of the stroke, but that theoretically the increase should be $3\frac{1}{3}$ times instead of only $2\frac{1}{4}$;—therefore the actual efficiency of steam increases with expansive working, at a much slower rate than would be possible if every drawback were extinguished. Atmospheric resistance cannot as

yet be removed; but a material advantage would result from a reduction of the clearance between the valve and the piston.

As 75 per cent. is the greatest admission materially required under the link-motion, the relative efficiency for that admission, (1·18), being compared with the efficiency (2·22) for 10 per cent. of admission, they are as 1 to 1·9, or nearly 1 to 2; and it follows that under the most favourable existing circumstances, *the utmost possible efficiency of steam worked expansively* in locomotive engines by the link-motion *is about twice* that of the steam when worked under *full gear;* that is, the *same quantity of steam* does *twice the quantity* of work.

The effective mean pressure is to some extent affected by the speed; but to find the average rate of increase with the admission, take the means of the maximum and of the effective mean pressures in Table No. 3, cols. 3 and 9, as follows:—

No. of Notch.	Average Maximum Pressure in Cylinder.	Average Effective Mean Pressure in Cylinder.	
		Pressure.	Per Cent. of Average Maximum Pressure.
	lbs.	lbs.	Per. Cent.
1	82	68·2	83
3	80	54·5	68
5	82	36·1	44

The per-centages in the last column may be arranged in a curve, see (Fig. 7, Plate 55,) having the base line AB to represent the stroke, and the perpendiculars at E, F, G, equal to the respective per-centages measured on a vertical scale. The curve must pass through the point A, as, when no steam is admitted, no work can be done; the other end at D must also terminate somewhere *below* 100 by the scale, as even with an entire admission something must come off for back pressure. From the curve, the following formula is derived for finding the per-centage of effective mean pressure due to a given admission, in terms of the maximum pressure:—

Let A = the percentage of Admission, and P = the percentage of Effective Mean Pressure, then

$$P = 13{\cdot}5 \sqrt{A} - 28 \quad \text{- - - - - - - -} \quad (3).$$

RULE 3.—*To find the Effective Mean Pressure in the Cylinder, in terms of the maximum pressure, for a given per-centage of admission.* Multiply the square root of the percentage of admission, by 13·5, and subtract 28 from the product; the remainder is the Effective Mean Pressure in per-centage of the maximum pressure of steam admitted.

The results by this rule are rather too small for lower speeds, and rather too great for higher; but the deviations are of no practical moment. At 40 miles per hour, or 560 feet of piston per minute for the "Great Britain," the result exactly coincides with practice; and this is an ordinary speed of piston in both Goods and Passenger Engines, as, though the usual speed of the former on the rails is less than that of the latter, the wheel is smaller, and the stroke is commonly longer. The rule applies very well to admissions between 10 and 75 per cent., and to pressures (maximum) from 60lbs. to 100lbs., or even 150lbs.

The following Table, No. 5, of Effective mean Pressures, is calculated by means of the foregoing rule, for admissions advancing by twentieths of the stroke, or intervals of 5 per cent.; and, fortunately, most of them may be accurately expressed in common fractions, as in the last columns of the table.

In all well-protected cylinders, with blast-orifices, not less than $\frac{1}{16}$th of the area of the cylinder, the foregoing rules and tables of data apply to the action of steam at speeds under 30 to 40 miles an hour. For speeds amounting to 55 to 60 miles an hour, the loss by imperfect exhaust causes a large increase of consumption per horse-power per hour, of from 33 to 12 per cent., according to the amount of admission. With steam-ports of about $\frac{1}{14}$th, and blast-orifices $\frac{1}{14}$th of the cylinder, the rules likewise apply, at speeds under 30 to 40 miles an hour. At the higher speeds, the useful power is considerably impaired by imperfect exhaust.

TABLE No. 5.—*Effective Mean Pressure in the Cylinder, for various Admissions.*

For Maximum Pressures of 60 lbs. to 150 lbs.

Periods of Admission in parts of the Stroke.	Effective Mean Pressures, in parts of Maximum Pressure.	Periods of Admission in common fractions of Stroke.	Effective Mean Pressure, in common fractions of the Maximum Pressure.
Per Cent.	Per Cent.		
10	15	1-10th	1-7th full.
12·5	20	—	—
15	24	1-8th	1-5th
17·5	28	—	—
20	32	1-6th	1-4th
25	40	1-5th	1-3rd
30	46	1-4th	1-2·5th
35	52	1-3rd	1-2nd
40	57	—	—
45	62	—	—
50	67	1-2nd	2-3rds
55	72	—	—
60	77	—	—
65	81	2-3rds	4-5ths
70	85	—	—
75	89	3-4ths	9-10ths

The proportions of the "Great Britain" may be applied to any other engine, and they may be repeated here as standard ratios for practice, until superior results are obtained.

Sectional area of cylinder 1
,, steam-port 1-10th
,, blast-orifice 1-11th
Lap of valve, $1\frac{1}{4}$ inch.

Travel, $4\frac{3}{4}$ inch, in full-gear,
Lead, $\frac{1}{4}$ to $\frac{3}{8}$ inch.

So wide a blast-orifice as $\frac{1}{11}$th, is a rare thing in Locomotives; but the writer is satisfied that even in engines of very unfavourable proportions otherwise, a very wide orifice may be obtained by the proper adjustment of matters of detail.

In a second part of this paper, the writer proposes to discuss the *conditions* necessary for the successful expansion working of steam in Locomotives.

The following is a comparison of the actual results of Engines working with ordinary *Gab-motions*, and with *Link-motions.*

The engine "Europe," on the Edinburgh and Glasgow Railway, cylinder 16 X 18 inches, wheel 6 feet. Doing one week's work, in 1849, with *gab-motion*, consumed an average of 19 cwt. of coke per day, and 2 cwt. of coal. As, in the locomotive boiler, coal is about two-thirds of the value of coke, 2 cwt. of coal is equivalent to 1.33 cwt. coke; and the consumption per day may be stated at 20.33 cwt. coke.

The same engine, fitted with *link-motion*, used at the same season in 1851, and doing the same work, 12 cwt. of coke, and 3 cwt. of coal daily, equivalent to 14 cwt. coke: over a run of 94 miles, the expenditure becomes

24·22 lbs. per mile with gab-motion
16·70 ,, ,, link-motion

7·50 lbs. reduction, or 30 per cent. with link.

The periods of admission in the two cases would be about 70 and 45 per cent., and by the Table of Efficiency, the consumption would be as 1·50 to 1·23, showing an economy of only 18 per cent., or barely two-thirds of what was actually made. The greater actual efficiency must in great part be due to the superior opportunity of working with high pressure, during the admissions afforded by the link.

Again, the test may be applied by measuring the water consumed. The following are a selection of cases from the writer's own experience and observation.

Engine with Link-motion, cylinder 15 X 20 ins., wheel 6 feet.
Edinburgh and Glasgow Railway.

		Mean Speed. Miles Per Hour.	Average Train of Carriages.	Consumption of Water in feet, pr. Mile.	
1851. 26 Aug.	"Orion," ordinary train.	19·6	16	2·97	Stiff Wind ahead.
,, ,,	Do. do.	24·4	7	2·01	Do. favourable.
27 ,,	Do. do.	24·4	7	2·22	Do. ahead.
,, ,,	Do. Express	32·0	5	1·65	Do. favourable.
1850. 7 Sep.	Do. do.	32·7	5	1·65	Slight wind ahead.

Engines with fixed Gab-motion, cylinder 16 X 18 ins., wheel 6 feet.
Edinburgh and Glasgow Railway.

1850. 3 Sep.	"America, ordinary	21·5	13	3·01	Wind favourable.
10 Oct.	"Nile," Expr.	29·0	7½	3·00	Do. ahead.
21 ,,	"Niger," ,,	—	7	2·80	Calm.

Express Engine, with fixed Gab-motion, cylinder 16 X 18 ins.,
wheel 6 feet. North British Railway.

1851.	Express	38·5	5	2·70	Calm.
	,,	38·5	5	2·70	Do.
	,,	38·5	4	2·96	Wind ahead
	Mail	35·7	7	3·05	Calm.
	Ordinary	22·0	12	3·45	Calm.

These results show, as before, that under similar circumstances, what has been deduced from an independent examination of Indicator-diagrams, taken under the Link-motion, as to the *economy* of steam *worked expansively*, is fully borne out by a direct appeal to the relative consumption of coke and water.

The CHAIRMAN observed that he felt much obliged to the author of the paper for explaining in such a clear and practical manner the action of the slide-valve and the link-motion; and the paper was particularly valuable for the actual numerical results that were given so completely of the variations in practical working, showing the improvements effected and the defects avoided.

Mr. McCONNELL considered the practical investigation of the subject given in the paper was very valuable. He agreed that the link-motion was the most advantageous and useful of any valve-motions known for Locomotive engines; and the mode of hanging the link from a fixed centre, adopted by Mr. Gooch in the Great Western engines, had the advantage of preventing the increase of lead that took place in the ordinary link-motion when working with much expansion. He considered that the surcharging of the steam in the smoke-box was a valuable suggestion, and might very probably admit of being carried out so as to effect an important economy. And he thought that a hot-air chamber should be contrived, passing round the cylinder, and kept constantly in such a temperature as to prevent any condensation of steam during expansion, and ensure the steam being always maintained perfectly dry, without any water being ever present in the cylinder from condensation or priming. The suspending the cylinders in the smoke-box was a good plan in the Great Western engines, but a special arrangement was required for the purpose of thoroughly carrying out the principle in a proper manner.

Mr. CLARK said that in the engines referred to, Mr. Gooch had carried the steam pipe straight down in front of the tubes, instead of curving it on one side as usual, and the pipe being made of one-eighth inch copper, the heat from the tubes was rapidly communicated through it, and the steam became much heated. In the experiments with the Great Britain engine, it

had been found that there was considerably less difference between the pressure of the steam in the boiler and that in the cylinder, than was the case in other engines where the steam did not get so much heated; and Mr. Gooch had found in repeated experiments, very carefully tried, that the pressure was actually a little higher in the steam chest than in the boiler, the difference being greater at a higher speed, and amounting to as much as 7 to 10 lbs. per inch in some cases, the pressure in the cylinder being equal to that in the boiler, and in some cases 2 or 3 lbs. above, instead of being considerably below, as was the case in most engines in regular work. He could only suppose that the elastic force of the steam was increased by its becoming surcharged with heat in the smoke-box after leaving the boiler, but could not account for a greater pressure being apparently maintained in the steam chest, whilst the steam was flowing into it from the boiler.

Mr. Slate could not see how a greater pressure could exist in the steam chest than in the boiler, as the steam would in that case flow back to the boiler till the pressure was equalised.

The Chairman observed, that with regard to the question of surcharging steam, he remembered being told by Mr. Trevithick of an experiment which he made in Cornwall in 1830. He had to repair an old engine there, which had no steam jacket to the cylinder, as most of the other engines had, to keep up the pressure of the steam; and he built a brick casing round the cylinder, leaving an air space all round, and applied a small fire to keep this air heated. About one bushel of coals in twenty-four hours was consumed in heating the cylinder, and he found a great increase was effected in the duty performed by the engine, with the same consumption of fuel under the boiler as before. He then removed the fire from the cylinder, in order to find the relative efficiency of the coal when consumed under the boiler or under the cylinder, and he found that it took five bushels of coals applied to the boiler to produce the same effect as the one bushel of coals applied to the cylinder.

The Chairman said, he had been so much impressed with the results of this experiment, that in the Planet, one of the early locomotives made in 1832, he had the cylinders carefully enclosed inside the smoke box instead of being outside, and there was found to be a considerable increase of power effected by the plan. That was the first locomotive constructed with heated cylinders, and it appeared the principle ought never to have been deserted; but it was singular how temporary prejudices sometimes caused a good thing to be departed from. Those inside cylinders were abandoned because the crank axles were found liable to break, but then after that objection was subsequently removed by improved manufacture, the prejudice against the inside cylinders still remained; however, they appeared now to be going back to them. The construction of locomotives was still perhaps much influenced by these local prejudices arising from individual circumstances; and he was confident that this Institution would conduce greatly to the removal of them, by the mutual interchange of ideas and experience that was promoted by it; and nothing could assist more in forwarding such a desirable object than the reading of such papers as the present one by Mr. Clark.

He quite agreed with the opinion stated in the paper on the great drawback to the application of expansion in locomotive engines caused by the condensation, from the cylinders not being heated; he considered some additional heat was required to be supplied during expansion to prevent condensation taking place, as it appeared the quantity of heat in steam was not sufficient to maintain the whole in the form of steam during expansion, but a portion returned to the form of water, as shown in the able investigation of the expansion of steam given in Lardner's Treatise on Heat.

Mr. Cowper described some experiments that had been made by Mr. Siemens and himself, which he thought showed that condensation did not take place during expansion. They took a cylindrical tin vessel closed at the top, about twelve

inches high and two inches diameter, the metal of which was very thin, and coated thickly with felt outside to prevent any loss of heat. A small steam pipe was connected at the top, but the bottom of the cylinder was open to the atmosphere; and a stream of 30 lbs. steam was blown into the vessel from a very small orifice, and allowed to escape freely into the atmosphere at the open end of the cylinder. After a short time, when the cylinder had become hot, and was maintained just full with expanded steam at the atmospheric pressure, a thermometer inserted a short distance into the open end, showed a constant temperature of 214° to 215° instead of 212°, proving the total quantity of extra heat that is in high pressure steam; and no condensation could be perceived inside the cylinder, no vapour being visible until the steam had escaped from the cylinder into the atmosphere. This experiment was tried on several different occasions, and on one it happened that the boiler was priming slightly; and when a drop of water came over through the steam pipe and dropped upon the bulb of the thermometer, it was observed to fall suddenly to 212°, and remained at that point until the water was boiled off, when it again rose 2° to 3° above the boiling point as before. The experiment had been suggested by Mr. Siemens, and was a very ingenious one.

The Chairman said, he did not think that mode of trying the experiment would give a correct result as regarded the present question, as the steam was escaping into the atmosphere instead of being all confined within the cylinder, and the temperature in the cylinder being maintained above the boiling point would prevent any condensation taking place during the expansion of the steam.

Mr. Cowper did not think that in a cylinder that was thoroughly protected from loss of heat by radiation or conduction, any condensation of the steam would take place during expansion, and that if any condensation occurred, it would be found to be owing to the steam having lost some of its heat, which it could not recover. The result that he obtained by

indicator diagrams from a pair of 35 horse-power, high-pressure, expansive, and condensing engines, which he had constructed some years since, fully bore out this view; the steam was expanded in the cylinder of each engine independently, and the practical expansion curve was obtained very accurately. The whole body of the cylinder was necessarily nearly at a mean temperature between the highest and lowest steam in the cylinder, (the cylinder not having a steam jacket,) consequently the steam ought to be slightly cooled on entering the cylinder, and towards the end of the stroke, where it was at a lower temperature from expansion, it ought to be slightly warmed by the cylinder;—now the indicator figure showed both these circumstances to have taken place, for the actual curve during the first part of the stroke, after the steam had been cut-off, was rather below the true expansion curve, and during the latter part of the stroke it was rather above; this also showed that the expansion curve required a slight correction for the extra quantity of heat in the high-pressure steam.

Mr. Clark remarked that he had found by the indicator diagrams, that a great condensation of the steam took place in exposed outside cylinders during the first part of the stroke, from the coldness of the cylinders, and a considerable amount of condensation also was caused even in protected cylinders, where they were not artificially heated by exposure to the hot air in the smoke-box, because the temperature of the mass of metal in the cylinder remained about the mean temperature of the steam whilst expanding in the cylinder, which might be many degrees below the original temperature of the steam on entering from the boiler. This caused the actual pressure of the expanding steam to be below the theoretical pressure during the first half of the stroke, as shown in the indicator diagram, Fig. 3, Plate 56; where the theoretical curve of expansion is shown by the dotted line BCD, allowing for the contents of the steam port and the clearance represented by the space AA. But about the middle of the stroke, the two curves

coincide at C, as the steam was then at its mean temperature, and agreed with the temperature of the cylinder; and after that point, as the steam continued to expand and lower in temperature, the cylinder remaining nearly constant was hotter than the steam, and returned some of the heat it had robbed from the steam, re-evaporating more and more of the water that had been condensed, and raising the curve of actual pressure above the theoretical curve at the end D, where the exhaust commences. A portion of the lost steam is thus restored in the second half of the stroke, but a serious loss of power still remains; and the consideration of this action that is always going on to a greater or less extent in the cylinders of Locomotives, however well they may be protected, except where they are artificially heated, shows what an important source of economy is to be found in carrying out that principle.

The Chairman proposed a vote of thanks to Mr. Clark for his valuable and interesting paper, which was passed.

The following paper by Mr. J. E. McConnell, of Wolverton, was then read:—

ON A NEW PORTABLE LIFTING MACHINE.

The object of this machine, which is the invention of Mr. Long, Royal Hydrometer Maker, London, is to obtain, in a portable and simple form, the means of multiplying the power of a man to a very great extent, for the purpose of lifting weights, &c., without the drawback of heavy friction and wear to which some lifting machines are liable, such as those in which an endless screw works into a toothed wheel. A specimen of this machine is before the meeting, and the construction is shown in Figs. 1 and 2, Plate 58.

A is a wheel, on which eleven pins, BH, are fixed in the form of teeth, with a friction roller fitted upon each pin.

The circular plate CC is fixed at right angles to this wheel, upon the shaft of the winch D, to which the manual power is applied. On this plate is cast the spiral projecting piece EFG, which makes rather more than one turn upon the plate. This spiral is engaged with the pins BH on the first wheel, and the difference in the amount of eccentricity of the two ends of the spiral is equal to the pitch or distance between the pins; so that when the plate C and spiral are turned round one revolution by the handle, the wheel A is driven round the distance of one pin or tooth.

The driving face of the spiral has a varying bevil, adjusted so as to bear fairly and uniformly upon each pin in succession throughout the entire revolution, as the pin varies its inclination from B to H; the next pin above, I, being then brought down into the position B.

The thickness of the spiral, as shown at G, nearly fills the space between the two pins at all times, preventing any slip, and the upper pin is engaged a short distance before the lower one is released.

The friction roller upon the pin turns round during the motion, rolling, with little friction, along the inner surface of the spiral, which forms an inclined plane, with an inclination of about 1 in 7.

A pinion fixed on the wheel A is geared into one of three times the diameter on the third shaft, K, upon which is fixed the drum L, for winding up the rope or chain attached to the weight to be lifted. The leverage of the spiral and first wheel being 11 to 1, and that of the spur gearing 3 to 11, makes a power of 33 to 1, and the radius of the winch handle and of the drum being 6 to 1, the total increase of power obtained by the machine is 200 to 1 very nearly; or one man exerting a power of ½ cwt. at the winch could lift five tons, including the friction.

This machine has the advantage of reducing the friction, in consequence of the rubbing action being confined to the revolving of the friction rollers upon their axles, instead of the inclined plane rubbing upon the pins, or the thread of an endless screw rubbing upon the teeth of a worm wheel, which has only contact at little more than a line. This has a scraping action, tending constantly

to remove the oil from the surface, but in the friction rollers there is a much larger surface in contact to bear the pressure, and this surface being always in contact never has the oil scraped off the surface, and can retain the oil for a much longer time.

The same principle of a spiral is applied in a convenient and efficient manner in the vice shown in Figs. 3 and 4, in which the projecting spiral acts upon the teeth of a straight rack, connected to the sliding jaw of a parallel vice.

Another application is also shown in Fig. 5, to a rack-pulley for a window-blind cord, in which the pulley can be conveniently tightened or slackened or removed as required, and is held in its place by the spiral.

Mr. McConnell exhibited one of the lifting machines at work, and specimens of the vice and rack-pulley. He said he had only lately become acquainted with the invention, and it appeared to him worth bringing under the notice of the meeting; there might be some other practical applications that would be useful on account of the reduction of friction in transmitting the power. The vice was a convenient form, as the jaws were always parallel, and the lever was out of the way of the man.

The thanks of the meeting were given to Mr. McConnell for his communication.

The consideration of Mr. Lamb's Marine-Engine Boiler was postponed in consequence of the absence of the author.

The Chairman announced that the next Meeting of the Institution would be an additional meeting in London, in June, for which some valuable papers were in preparation; and he congratulated the members on the prosperous position of the Institution, and its increasing efficiency and usefulness.

The Meeting then terminated, and the members adjourned to the library, where coffee was served, and several interesting objects were exhibited.

M. BOURDON, from Paris, exhibited several varieties of his Manometer or pressure-gauge for steam boilers and other purposes, with a series of models, illustrating the principle on which the instrument is constructed; namely, a flattened metallic tube, bent into a circular curve, and acted upon in the interior by the pressure of the steam, &c., causing the curvature to diminish and the detached end of the tube to move in proportion to the degree of pressure, and indicate the pressure by moving the index on the dial, the tube being elastic. These instruments were stated to be found very correct in practice, not liable to derangement or inaccuracy, and convenient in application as steam-pressure gauges, vacuum gauges for condensers, or pressure gauges for gas, &c.; and were adopted for general use by the government inspectors of steam-boilers in France. A portable barometer was exhibited, constructed on the same principle and similar in form to the aneroid barometer. Also an ingenious instrument for measuring velocity of rotation, founded on a property of the peculiar form of curved tube that was employed in the above instruments, to increase its internal capacity in proportion to the diminution of its curvature; this instrument was proposed to be brought before the Institution in a more complete form.

Mr. FOLLETT OSLER, of Birmingham, exhibited to the members an extensive series of diagrams, taken from his new compound self-registering Anemometer, fixed at the Liverpool Observatory. This instrument is a further improvement on the former self-registering Anemometer constructed by Mr. Osler, and erected at the Birmingham Philosophical Institution in 1840; described in the Transactions of the British Association. In this instrument, in addition to the constant record of the *direction* and *force* of the wind, by two lines traced by the instru-

ment itself, upon a continuously moving sheet of paper, the *velocity* is recorded by a third line, and the *quantity* by a fourth line. The *direction* and *force* are recorded by two pencils upon one flat sheet of paper, which is changed every day, and is fixed on a table moved at a uniform rate by a clock, and having the successive hours, &c., marked upon it. The *direction* pencil is moved in a straight line across the paper by means of a quick-threaded screw geared to the wind vane, tracing on the paper a waving longitudinal line, the paper being ruled longitudinally by fixed pencils to mark the cardinal points; the wind-vane is similar to the fan-wheel at the back of a windmill. The *pressure* pencil is moved transversely upon the paper by connection through wires with the pressure-plate, a circular disc four square feet area, which is held always at right angles to the direction of the wind, to receive the full pressure upon springs at the back, which yield according to the degree of pressure; a fixed pencil rules the datum line upon the paper.

The *velocity* and *quantity* are recorded on a continuous sheet of paper which is moved by the wind itself, at a rate exactly proportionate to the velocity of the wind; the successive hours being marked upon the paper whilst passing, by means of a punch which is in connection with the clock, and strikes a blow on the arrival of each hour. The distances between these successive hour-marks on the paper, give consequently by a scale the measure of the *velocity* of the wind at each time; and the total length of the paper that is passed in an hour or a day gives the measure of the total *quantity* of air that has passed the place during the time, one inch of the paper representing thirty-eight miles of air. The length of one sheet of paper was thirty-one feet, for the month of January last, representing that the total quantity of 14,000 miles of air had travelled past the place during the time; that quantity being the sum of all the currents of air in all directions at that particular place. The motion of this paper is obtained from a vertical spindle which has four horizontal arms, three feet long, fixed on the top at right

angles to each other, each carrying at the extremity a hemispherical cup, eight inches in diameter, fixed vertically, so that when one presents its hollow side to the wind, the opposite one presents its convex side in the same direction. The moving power of the wind upon the convex side is only one-half as great as its power on the hollow side, and consequently the whole instrument is caused to revolve; but as the hollow side moves with the wind, and the other against it, the result is that the instrument revolves at the rate of one-third the velocity of the current of air. (This plan, having been originally discovered by Mr. Edgeworth, was first applied to Anemometers by Dr. Robinson). For the purpose of ascertaining the variations in the velocity of the current, when an unusually large quantity of air is passing, as in the case of a storm, there is an additional marking apparatus which can be thrown into gear with the clock, and strike a mark on the paper at every minute, or five minutes, or quarter of an hour, as desired, during the continuance of the storm, and be then discontinued when the velocity of the paper is sufficiently diminished. This instrument is the first that has been constructed of this compound kind, and it has continued in constant work for about half a year with entire success; it has stood without any injury or derangement the trial of a very severe storm on 9th January last, when the pressure of the wind reached to 29 lbs. per square foot, as recorded on one of the sheets exhibited, and the greatest velocity was 62 miles per hour.

Mr. EDWIN COTTERILL exhibited his improved Bank Lock, and a number of specimens of different ingenious applications of the principle of his lock. The large Bank Lock, which received great attention and commendation from the members, is shown in Plate 59. It consists of a series of 24 radiating steel slides AA, shown in the section Fig. 3, and in the elevation Fig. 5, (which has the front plate removed, as well as the centre piece, shown separately on a larger scale in Figs. 1

and 2.) The slides AA move in radiating channels in the main barrel of the lock BB, and each slide is pressed to the centre pin by a separate spiral spring C C. A circular groove D D, is cut in the face of the barrel and of the slides, (when the slides are forced outwards to their right positions by the insertion of the key,) so that a continuous circular channel is formed by the coincidence of the different portions of the groove in the face of the barrel and the notches so cut in the several slides. Into this circular channel enters the notched ring E, (shown separately in Fig. 4,) which is fixed to the top frame of the lock FF, and remains stationary, whilst the barrel B, with the set of slides and springs, revolves with the key. But when the key is withdrawn, each of the slides is forced in different degrees towards the centre by its spiral spring, sliding also through the several notches in the fixed ring E, so that their solid portions intercept the groove in the barrel, (as shown in Fig. 5), and in this position the barrel is held fast by the fixed ring E, and the lock is prevented from turning. The key, shown in Fig. 7, consists of a cylindrical stem, having a series of radiating grooves cut in its circumference, corresponding to the slides in the lock; these grooves are inclined in the bottom, and they all vary in depth, length, and the angle formed by their bottom with the axis of the key. When placed in the lock for the purpose of opening it, the key is pressed down to the bottom, and each slide entering one of the grooves of the key, they are forced outwards by the inclined bottom of the grooves, to the various distances according to the depth and form of the grooves; and when the key is pressed home the notches in all the slides exactly coincide with the circular grove in the barrel, leaving a clear passage for the notched ring E, and the barrel, with all the slides, is then turned round with the key by means of the projecting bits on the key. Should an attempt be made to open the lock with a false key, one or more of the slides would be pushed too far, or not far enough, and then it would intercept the circular groove D, and prevent the barrel from turning, by locking it fast with

the fixed ring E. The revolution of the barrel B, causes all the bolts of the lock to be thrown, by the toothed ring G, fixed upon the out-side of the barrel, working into the wheel H, on the axis of which is the pinion I, that turns the wheel K, and this throws the bolt L, by means of the pins forming a rack upon the end of the bolt. The other bolts MM, (16 in all), are thrown by similar wheels NN, which are all driven simultaneously with the wheel K, by means of the toothed ring O, which revolves loose on the barrel B, and gears into each of these wheels.

The centre piece, shown separately on a larger scale in Figs. 1 and 2, (elevations taken from the inner side) contains the "nosle-drop," P, which is a steel plate, closing the keyhole Q, and prevents the key from entering the lock, until it is removed into the position shown in Fig. 2, by the key making one revolution previously, and turning round the inner cylinder R, which moves the drop on one side by the pin on the cylinder at R, and the key is then ready to enter the lock, the key-hole being again instantly closed by the drop when the key is removed, by the spring pressing it over the pin, which slips under the drop in that position. But the cylinder R, has a notch S, which is locked by the vertical slide T, (shown unlocked in Fig. 2, and altogether removed in Fig. 1); and it cannot be made to revolve until this slide T, is withdrawn by means of the safety key or "sentinel" shown in Fig. 6, which turns round the barrel U, (Fig. 2), and draws down the slide T, by the projecting bit on the barrel acting on the notch in the tumbler V, which is centred at the top upon the slide T. This tumbler is pressed up by a spring, Y, and has an L-shaped slot, in which a fixed pin works, and this pin holds down the tumbler and slide, when pressed into the horizontal part of the slot by the action of the bit on the revolving barrel, U. This holds down the slide T, and prevents it from again catching the cylinder R, until the main key is put into the lock; but directly the main key begins to turn, the rocking lever W, which had before rested on a flat

place in the cylinder R, is thrown out by coming in contact with the circumference of the cylinder, and the lower end of the lever W, presses in the tumbler V, and releases it from the pin by bringing it into the vertical portion of the slot in the tumbler, which is then pressed up by the spring Y; and the slide T, is pressed against the cylinder R, ready to lock into the notch S, directly it comes opposite. The "sentinel" key, (Fig. 6,) is a complete counterpart of the main key on a smaller scale, and acts on a complete lock on the same principle, with six radiating slides, and having the key-hole closed by a "nosle-drop" X, in the same manner. Consequently, before the main lock can be opened, the sentinel key has to be turned once round to open its own key-hole, and then pressed home to move the slides in its lock to the right position, for enabling the key to turn a second time and unlock the catch from the main key-hole; the main key is then put in, and by the first revolution in the same manner opens its key-hole and is then pressed home, and by a second turn the lock is opened. This operation, though apparently complicated, is in reality as simple as unlocking two successive doors of the bank safe, both having been double-locked; but by this plan extreme security is obtained, as a lock of great security has first to be picked before the key-hole of the main lock can be opened, and any steps taken towards picking it.

A further security is obtained by means of a detector slide, which is attached to one or more of the slides in the lock, so that if any one of those slides is pressed out too far by a false key or otherwise, although the slide were brought back to its right place, the detector slide would remain projecting into the circular groove, forming an effectual obstruction to the revolution of the barrel; and this obstruction could not be removed even by the right key in the ordinary manner, thereby detecting the attempt upon the lock, until the key was first turned backwards for a certain distance, which draws back the detector slide into its place, and restores the lock to its ordinary state. The keys

are cut by a machine for the purpose, which admits of being varied whilst working, to such an extent, that the key of every lock is made different, two only being cut alike as duplicates for each lock; the key is made first in each case, and the lock is formed to the key, by the slides being fitted to the key, the circular groove in the barrel and slides being cut simultaneously whilst the key is in its place; the form of the grooves of the key gives it the peculiar advantage that an impression cannot be taken from it, and the difficulty of making a correct duplicate of the key is so extreme, (except by the original cutting machine whilst adjusted to cut each groove of the first key), as to prevent risk of the key being copied. The slides being firmly guided in the grooves of the barrel, and the key-hole securely closed by the nosle-drop, protects the lock effectually from injury by violence from gunpowder or otherwise.

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PROCEEDINGS.

June 29, 1852.

The Special General Meeting of the Members was held at the Rooms of the Society of Arts, John Street, Adelphi, London, on Tuesday, 29th June, 1852. The Chair was taken by J. E. McConnell, Esq., Vice-President, in the unavoidable absence of the President, Robert Stephenson, Esq., M.P.

The Secretary read the Minutes of the last General Meeting, which were confirmed.

The following Paper by Mr. Andrew J. Robertson, of London, was then read :—*

ON THE MATHEMATICAL PRINCIPLES INVOLVED IN THE CENTRIFUGAL PUMP.

Centrifugal Pumps, the principles of which form the subject of the following paper, will no doubt be remembered as occupying a conspicuous position in the Great Exhibition of last year. The first impression on seeing these pumps, was naturally surprise, that so simple a machine, and occupying but little space, should be capable of throwing so great a volume of water.

Simplicity is, no doubt, a very great merit in itself, and when it can be obtained, without the sacrifice of other things of more importance, is extremely desirable; moreover, this characteristic of the pump in question gives it a peculiar advantage in practice, which will be more particularly alluded to hereafter; but before a correct judgment can be formed of its merits as a whole, it is evidently necessary to compare not only the proportion between the size and effect, but between the *power* required to be expended, and the *useful work* accomplished.

It is unnecessary for the present purpose to enter into any description of the details of these pumps. Their form may be varied according to circumstances; for instance, they may have one, two, or six

* The Secretary explained that this paper had been incorrectly announced as by Mr. Michael Scott of London, and was written by his assistant Mr. Robertson, to whom the credit and the responsibility of the paper were due.

arms. In discussing the general principle, it will be sufficient to take a form which, while it embodies the principle completely, will serve to set it in the clearest light.

The Pump may, then, be said to be composed of a horizontal arm or pipe A, in Fig. 1, Plate 60, and a vertical pipe B, dipping into a cistern C, from which the water is required to be raised; the whole is supported in such a manner that B constitutes an axis, about which the machine is made to revolve by means of a steam engine acting on the crank D. Suppose that the arm is filled with water, as shown in the figure, and that the arm is in motion; the water contained in the arm A has then a centrifugal force, the amount of which depends upon the angular velocity with which it is revolving. It is manifest that this velocity must be such as to produce a centrifugal force, equal to the weight of a column of water of the same section as the arm, and of a length equal to the height of the discharge pipe above the surface of the water in the cistern, in order that the column of water in the pipe B may be supported.

When this velocity increases, the centrifugal force is in excess, the water flows through the arm A, and is delivered into a conduit to take it off. The amount of this delivery depends therefore upon the excess of the angular velocity above that required to keep the arm full.

The question we have now to examine is, what is the power required to drive this Pump, and what is the useful effect, estimated by the product of the quantity delivered, by the height which it is raised.

Let a be the angular velocity of the arm.

R the length of the arm in feet, and consequently the radius of the circle described by the extremity.

G the distance in feet of the centre of gravity of the water contained in the arm, from the centre.

Let the area of the section be constant throughout its length, and equal to unity, and let w be the weight of the water contained in one foot of the arm.

$$\text{Then the whole weight } W = R\,w, \text{ and } G = \frac{R}{2}$$

$$\text{And the centrifugal force} = \frac{a^2}{g}\,W\,G* = \frac{a^2\,R^2}{2g}\,w$$

* Moseley's "Mechanical Principles of Engineering and Architecture," Equation 103, p. 125.

Or, for the sake of simplicity—

$$\text{Let } w = 1\text{, then the centrifugal force} = \frac{a^2 R^2}{2g}$$

Now a R is the actual velocity with which the outer end of the arm is moving, and $\frac{a^2 R^2}{2g}$ is the height due to that velocity.*

The centrifugal force of the water is therefore represented by the weight of a column of water of equal section with the arm, and of a height equal to that due to the velocity of the end of the arm. And, as was observed before, the part of this column which is effective in *producing a flow* through the arm is the *excess* of the height of this column above the height of the orifice of discharge, reckoned from the surface of the water in the cistern.

What, then, is the velocity of flow so produced?

In estimating the effect of the centrifugal force, the velocity required to be communicated to the water in the vertical pipe may be neglected for the present, because by increasing the area of its section relatively to that of the arm it may be reduced considerably, and for the sake of simplicity, it may be considered as nothing. This subject will be alluded to hereafter.

Let AB, in Fig. 2, Plate 60, be a pipe of equal section throughout.

Let the water in it be in motion. After a small period of time, the water which occupied the space AB will occupy the space CD. The portion CA drops off, and an equal quantity of water DB, at rest, is added.

The portion DB is put in motion suddenly, by virtue of its continuity with the water in AD, but in thus being put in motion it reacts upon the water in AD, and checks its velocity.

Now suppose that, instead of being added at rest, DB had a motion equal to that of the bulk of the water, no retardation would be produced; and conversely, if that water be moving through the arm with the velocity with which the portion DB can be constantly added, that velocity will be maintained uniform. But the velocity with which DB can be added is that due to the head of water acting on the arm, and therefore the velocity of flow is that due to the excess of the

* Moseley's "Mechanical Principles of Engineering and Architecture," Equation [illegible], p. [illegible].

column representing the centrifugal force above the length of the vertical-pipe.

If h be the length of the vertical pipe, then $\frac{a^2 R^2}{2g} - h$ is the effective head, and the velocity of flow is $\sqrt{2g\left\{\frac{a^2 R^2}{2g} - h\right\}} = \sqrt{a^2 R^2 - 2\,gh}$ Let the velocity of the water at the end of the arm be V, and that due to the length of vertical pipe $h = v$, then the velocity of flow $= \sqrt{V^2 - v^2}$ and since the area of the section of the arm is unity, the discharge per second is also represented by the same expression $\sqrt{V^2 - v^2}$

Next—to estimate the amount of power required to be expended upon the machine to produce this discharge.

Every particle of the water contained in the arm has the same circular motion as the part of the arm it is in.

The water, therefore, as it leaves the arm, has a velocity equal to that of the outer end, and its direction would be a tangent to the circle described by the end.

But it has also a velocity (that of the discharge) in the direction of the length of the arm, or the radius of the circle; its actual motion, therefore, in magnitude and direction, will be represented by the diagonal AE of the parallelogram ABED in Fig. 3, Plate 60, one side of which, AD, represents the first velocity above mentioned, and AB or DE the other.

What we are concerned about at present is the amount only of this velocity.

$$AE^2 = ED^2 + AD^2 = AB^2 + AD^2 = (V^2 - v^2) + V^2 = V^2 - v^2$$

The number of units of work accumulated in a body moving with a given velocity (which is the power required to be expended to produce that velocity) is represented by the formula—

$$U = \tfrac{1}{2}\,\frac{w}{g}\,v_1^2\,*$$

where v_1 is the velocity, and w the weight.

$$\text{In the present case } v_1^2 = 2\,V^2 - v^2$$

$$w = \text{discharge per second} = \sqrt{V^2 - v^2}$$

$$\therefore\ U_1 = \frac{(2\,V^2 - v^2)\,\sqrt{V^2 - v^2}}{2g}$$

* Moseley's "Mechanical Principle's," &c., Equation 44, page 69.

But not only is the water now in motion which was formerly at rest, but it is in motion at a *higher level*. The total number of units of work which must therefore have been done upon the machine, is the sum of the number of units expended in producing motion, and the number expended in raising the water to the height h or $\frac{v^2}{2g}$, which is represented by

$$U_2 = \frac{v^2}{2g} \sqrt{V^2 - v^2}$$

Therefore the *total power* expended is equal to

$$U_1 + U_2 = \frac{V^2}{g} \sqrt{V^2 - v^2}$$

or the *power* expended on the machine is measured by the quantity of water delivered, raised to *twice the height* due to the velocity of the circumference of the arm.

As to the *useful effect* produced, it is simply the water delivered raised to the height h, or $\frac{v^2}{2g} \sqrt{V^2 - v^2}$

Since a body in motion is, theoretically, always capable of raising itself to a height due to the velocity, it will be clear that the water when delivered with considerable velocity must be capable of doing work, either by impinging upon a machine to which it might communicate motion, or by raising itself to an additional height; and if the power thus inherent in the water could be taken advantage of without interfering with the discharge, the result would be that the useful effect would equal the power expended; supposing for argument's sake that friction and such causes of loss did not exist.

But there are great practical difficulties in the way of recovering power from water in motion. The useful effect of an undershot water-wheel is only 33 per cent., and then the water flows with a full body in a confined channel; but in the centrifugal pump it flies off from all parts of the circumference of a circle. Had the direction of the motion been that of the radius of the circle, a dish of the shape shown at E in Fig. 4, Plate 60, would have guided the water, and it might have been delivered into a trough at a higher level. Even then, the friction of the surface of this dish would greatly diminish the velocity, and consequently the power of rising; but, unfortunately, as has been shown,

the direction is that of the diagonal of the parallelogram AE, Fig. 3, from which it will be evident that the length of the path which must be described by the water before the trough in Fig. 4 could be reached must be very much greater than in the case supposed above.

We must therefore come to the conclusion, that unless some means can be devised of recovering the power of the motion of the water, it must be thrown away, and consequently lost—for it is only by misapplication or waste that power can correctly be said to be lost, action and reaction being always equal.

The amount of this loss or *waste of power* is then—

$$\frac{V^2\sqrt{V^2 - v^2}}{g} - \frac{v^2}{2g}\sqrt{V^2 - v^2} = \frac{2V^2 - v^2}{2g}\sqrt{V^2 - v^2}$$

The expression vanishes, or the loss is nothing, when $v = V$, or when the delivery is nothing, that is, when the velocity of the circumference is that due to the height h of the arm above the water.

Since the total power expended is $\frac{V^2}{g}\sqrt{V^2 - v^2}$

And the useful effect is . . . . . . $\frac{v^2}{2g}\sqrt{V^2 - v^2}$

The per-centage of *useful effect* is $100\dfrac{\frac{v^2}{2g}}{\frac{2V^2}{2g}} = \dfrac{v^2}{2V^2} \times 100$

or the height to which the water is raised divided by *twice the height* due to the velocity of the circumference of the arm.

Suppose, then, a Pump required to throw a certain quantity of water, the velocity through the arm may evidently be made very little if the section be large; and the limit to which this enlargement of the section may be carried is imposed only by practical convenience. In this case, v^2 is but little less than V^2, and may be taken as equal in the left-hand factor of the expression for the waste of power, which then becomes—

Waste of power . . . . $= \frac{1}{2}\frac{V^2}{g}\sqrt{V^2 - v^2}$

Total power expended $= \frac{V^2}{g}\sqrt{V^2 - v^2}$

or the *waste* is exactly *one-half the power* expended.

Thus we see that the *limit* to which an *approximation* may be made, but which can never be practically realised, is that the useful effect should be half the power, or 50 per cent.

In the foregoing investigation the horizontal arm has been considered for the sake of simplicity to be situated at the upper extremity of the vertical pipe; in practice it is usually more convenient to place it in an intermediate position, having part of the column above and part below; this however does not affect the principle of the investigation.

Hitherto, the power absorbed by the velocity required to be communicated to each particle of water as it leaves the cistern and rises in the pipe B, Fig. 1, has been neglected, nor is it necessary to assign a definite value to it. By enlarging the pipe B, it may be greatly reduced, but as it can never be removed entirely, it constitutes one item of that loss which has to be deducted from the theoretical limit of 50 per cent.

There is, again, the friction of water in passing through the pipe B, and the arm A; and, lastly, there is the friction of the machine itself.

In Whitelaw's Mill, when a head of water is employed as a source of power, and where the waste arising from the communication of a circular motion to the water contained in the arm is avoided, the causes of loss just mentioned are in some respects the same.

The writer believes that in this machine the per-centage of useful effect has been found to be from 70 to 75 per cent. In estimating the useful effect likely to be realised by the Centrifugal Pump, we may take this as a guide, and since in this case 50 per cent. is the limit instead of 100 per cent., we have $\frac{75}{100} \times 50 = 37\frac{1}{2}$ per cent. as the practical result.

Although, therefore, the waste of fuel in employing this Pump is very great, it does not follow that it cannot be employed with advantage under any circumstances. There are many cases when fuel is cheap, and when it is consequently of greater importance to effect a saving in the first cost of a machine, than in the quantity of fuel which it consumes. Local peculiarities, too, may render it not only difficult to erect a Pumping Engine of the ordinary construction, which requires strong and heavy foundations, but even impossible.

In alluvial formations of great depth, a firm foundation can be obtained only at great expense. In such cases, the simplicity, the lightness, the cheapness, and it may be added, the portableness of such a machine as the Centrifugal Pump, are advantages which may greatly outweigh its want of economy in the consumption of fuel.

Mr. Buckle enquired whether indicator figures had been taken to ascertain, practically, the loss of power in work done by centrifugal pumps?

Mr. Stein (in the absence of Mr. Robertson, the author of the paper, who was prevented by illness from attending), explained that the paper was only intended to investigate the theory of centrifugal action, as applied to raising water, not the practical results of machines that had been constructed; the object was to show that the centrifugal action is not the one to be aimed at, being a losing action, as far as raising the water is concerned.

Mr. Buckle said he thought that in raising water it was best to lift the water by direct action, and there was a loss of power in giving it a circular motion.

Mr. Stein observed, that in centrifugal pumps there is not only the radial action from the centre to the circumference, but also that in the direction of the tangent; the former only is effective in raising the water, the latter being all lost, and only making the water revolve round a fixed centre, which absorbed so much of the power uselessly.

Mr. Buckle considered a balanced bucket-and-clack pump best for short lifts, and a plunger-pump with equilibrium clacks best for all high lifts. He asked what was the limit to the height to which water could be raised by centrifugal pumps?

Mr. Stein said there was, theoretically, no limit to the height, it only depended on the velocity given to the circumference of the arms.

Mr. Phipps thought that quite an erroneous view of the

question was taken in the paper. It supposed that the water issued from the arms with the full tangential velocity, which would involve a great loss, but that was not the case. He thought it might be put in a different way. Imagine that an elastic band round the periphery of the revolving arms confined the water, and represented the resistance to be overcome; this band would yield a little outwards, in proportion to the pressure, and give vent to an annulus of water at a slow speed, not at the great tangential velocity supposed, but at the rate corresponding to the difference between the internal and external pressure. He understood Mr. Appold's experiments with his centrifugal pump at the Exhibition gave an effect of 70 per cent. of the power expended.

Mr. Bishop could not see what became of the lost power, if so much of it was not effective as was argued in the paper.

Mr. Stein explained that the paper was only upon the principles of the true centrifugal pump; there were perhaps some rotary pumps which might involve another principle of lifting the water by an inclined-plane action of the oblique arms, which would not involve a loss of power to the same extent, but the investigation in the paper applied only to those pumps with radial arms, where centrifugal action alone was employed.

Mr. E. A. Cowper observed, that Appold's pump had curved or oblique arms, which would have an inclined-plane action to some extent in lifting the water.

Mr. H. Grissell said he had constructed two large pumps for draining purposes, on Appold's plan, which worked exceedingly well, lifting 8,000 and 10,000 gallons of water per minute. Mr. Appold had made experiments on the power employed, and had found, he understood, a result of about 70 per cent., but did not know the exact means by which the power was measured.

Mr. Phipps said he believed Mr. Appold had tried an experiment on the power consumed, by means of a Prony's friction-break, upon a centrifugal pump at his factory.

Mr. Edwards, of Birmingham, said he had manufactured several of Gwynne's centrifugal pumps, and he had recently tried an experiment with one that contained some further improvements of his own invention, having a revolving disc 13 inches in diameter, and driven at 800 revolutions per minute; it raised 650 gallons of water per minute to a height of 17½ feet, with a five-horse power steam engine, which he considered was equal to a duty of 70 per cent.

Mr. Crampton inquired whether the actual power had been measured that was developed by the engine, and employed in that experiment, by means of an Indicator or otherwise? He believed that an effect of 70 per cent. of the power employed had been found to be obtained in Appold's Pump at the Exhibition, but only about half that effect from Gwynne's Pump.

Mr. Edwards replied that the power had not been measured by an Indicator in his experiment, but had been calculated from the dimensions of the engine and the pressure of steam at the time, which he thought would be nearly correct. It was a high-pressure steam engine, with a cylinder 8-inch diameter and 18-inch stroke, working 100 double strokes per minute, and the steam was at 45 lbs. per inch; the back pressure, he thought, would not be more than about 2 lbs. per inch on the piston.

Mr. Buckle observed, that it was very deceiving to form any estimate of the power given out by a steam engine from the pressure of the steam in the boiler; and it was impossible to ascertain the effective moving pressure in the cylinder unless by taking indicator figures.

Mr. McConnell considered it was essential in such experiments to measure the power employed by means of indicator figures from the engine, or some kind of dynamometer, as no accurate practical results could be obtained otherwise; and he thought it was very desirable to obtain more correct data than appeared to be accessible at present, for a further discussion of so important a subject.

A vote of thanks was passed to Mr. Robertson for his Paper, and the discussion was adjourned to the next meeting.

The following Paper, by Mr. DANIEL K. CLARK, of Edinburgh, was then read, being the continuation of the Paper read by him at the last meeting:—

ON THE EXPANSIVE WORKING OF STEAM IN LOCOMOTIVE ENGINES.

In this paper it is proposed to consider the conditions on which the expansive working of steam in Locomotives may be most beneficially carried out.

The Condensation of Steam in the Cylinder by exposure, which takes place in certain arrangements of locomotives, is susceptible of proof in various ways: by the internal evidence of the indicator-diagram, in respect of its general form, the form and course of the expansion-line, and the back pressure; also, by a comparison of the volume of sensible steam which is found to pass through the cylinder, with the volume of water found by measurement to be consumed from the tender and the boiler. The evidence of the expansion-line of the indicator-diagram will be first considered, both for well-protected and partially-protected cylinders.

Of the Evidence of the Expansion-line of the Indicator-diagram.—By Regnault's experiments it is proved that the total heat of saturated steam increases slightly with the pressure, at such a rate that for atmospheric steam it is 1179° Fahr., and for 100 lbs. of steam it is 1217°, or 38° more. This difference is of little importance, except as it shows that when steam of higher pressure is expanded and falls to a lower pressure, it becomes slightly surcharged with heat as it expands, assuming that it does not part with any of its heat, and that there is *at least* no necessary condensation of steam during expansion, and that in fact there cannot be any, except what arises from the abstraction of the heat of the steam by external causes.

If water be present with the steam in the cylinder during expansion, as there commonly is, the heat of surcharge would convert a part of this water into steam. If 100 lbs. steam be expanded down to 20 or 30 lbs., the accession of steam in this way would be about $\frac{1}{40}$th of what is originally admitted; although the difference is so small, even for so prolonged an expansion, as not to require further consideration in the present inquiry.

The slow diagrams from No. 13 Caledonian Railway Engine, Fig. 1, Plate 61, supply examples of the results of condensation, and its influence in modifying the expansion-line. If the steam which is cut off be permitted to expand in the cylinder without any abstraction of its own heat, there can be no alteration of the whole quantity or mass of steam, whatever the change of volume may be; and the quantity of steam virtually saturated, indicated at the end of the expansion, or at any intermediate stage, should be found the same as at the commencement. If it be either greater or less, some change by condensation or otherwise must have taken place in the condition of the expanding steam. Referring to the diagrams from No. 13, (for which the points of distribution of the steam have already been given in the first paper)—if the whole clearance at the end of the cylinder, including the port, measured by $1\frac{1}{2}$ inches of stroke, be added to the volumes of the steam at the beginning and end of the expansion, the sums so found will be measures of the total initial and final volumes of the steam expanded, and the ratios of these volumes for each notch are contained in the 2nd column of table No. 6, following. The observed initial and final sensible pressures are added in columns 3 and 4. Dividing, in each case, the total volume of the steam, (equal to the product of the area of the piston and the length of stroke representing the volume) by the relative volume due to the pressure, the quotient is the water-equivalent, or the volume of water at 60° from which the steam is formed. The initial and final water-equivalents for each notch are entered in cols. 5 and 6, and their differences in col. 7, distinguished as positive (+) if in excesss of the initial quantity, and as negative (—) if in deficiency; the 8th col. contains the values of these differences as per-centages of the initial equivalents. In col. 9 are the pressures with which the expansion would have

terminated, had the initial quantity of steam in each case been preserved intact throughout the expansion; these pressures are found, in each case, by multiplying the relative volume of steam, of the initial pressure, by the ratio in col. 2, which gives the relative volume of the final body of steam, and consequently its pressure. Col. 10 contains the differences of the final pressures so calculated, and those actually observed, col. 4.

TABLE No. 6.—*Of the Expansion and Water-Equivalents of Steam in the Cylinder of No. 13. C.R.*

No. of Notch.	Ratio of Total Initial and Final Volumes.	Observed Pressures.		Water Equivalents.				Final Pressure due to an Equal Final Equivalent.	Difference of Final Pressures in Cols. 4 and 9.
		Initial	Final	Initial	Final	Difference of Initial and Final.			
	Ratio	lbs.	lbs.	Cubic ins.	Cubic ins.	Cubic ins.	Per Cent. of Initial	lbs.	lbs.
1	1 to 1·34	38	22	4·73	4·56	—·17	—3½	23½	+1½
2	1 to 1·58	41	19	3·99	4·01	+·02	+ ½	19	0
3	1 to 1·95	38	16	2·74	3·26	+·52	+19	10½	—5½
4	1 to 2·66	39	13	1·58	2·29	+·71	+45	4	—9
1	2	3	4	5	6	7	8	9	10

By tracing expansion-curves on the diagrams of No. 13, with the final pressures in col. 9, and otherwise such as would have been described with *a constant quantity of saturated steam* under expansion, the deviations of the actual curves from these, as standards, are easily shown. For No. 1 diagram, Fig. 1, Plate 61, the new dotted curves CD lies for its whole length *above* the actual, and terminates at 1½ lbs. more. For No. 2, the curves nearly coincide; for No. 3, the new curve proceeds for some distance above the actual, then crosses and falls lower as it advances, until it ends at 5½ lbs. below the other; for No. 4, the new curve AB passes on as in No 3, and ends at 9 lbs. below the actual. These deviations are all referable to one cause—*the condensation of the steam.*

In No. 1, the cylinder must have been at a lower temperature than the steam during the admission, and some condensation must have taken place, for no sooner is the steam cut off, than condensa-

tion is made visible by the sinking of the expansion-curve below the standard throughout the whole of its length. In No. 2, also, this takes place to a small extent for the first half of the curve, when the temperatures of the steam and the material of the cylinder become equal; after this, as the pressure continues to fall, and the temperature of the steam with it, the curve rises and meets the standard curve at the end, in virtue of a partial re-evaporation of the steam previously precipitated, caused by the cylinder itself, which, colder than the steam, and heated by it in the first stage of the expansion, is now relatively hotter, and partially restores the heat of which it had previously robbed the steam.

In Nos. 3 and 4, the process of successive condensation and re-evaporation is still more distinctly brought out. In these cases, the greater portion of the heat engaged in the restoration of the steam during expansion must have been absorbed by the cylinder, by condensation of the steam during admission. A reference to cols. 7 and 8 shows the magnitude of this condensing agency, for under the 3rd and 4th notches, the observed final equivalents are shown to exceed the initial by 19 and 45 per cent. of the latter respectively; which proves that, in the two cases, at least 19 and 45 per cent. of the steam admitted *must have been condensed during admission*, as the additional steam can have been obtained from no other source. Although the actual expansion-curves, Nos. 3 and 4, indicate much higher mean pressures, *during expansion*, than the standard curves, and may so far be viewed as superior results, the favourable difference is only a partial amends for the much greater loss by initial condensation; and an expansion-curve may be constructed backwards, in terms of the indicated mass of steam at the end of the expansion, to show from what initial pressure this mass of steam could have expanded, had there been no condensation. Take No. 4, for example. The final pressure at E is 13 lbs., for which the relative volume is 939, and the ratio of the initial and final total volumes, or the degree of expansion, is 1 to 2·66; then $939 \div 266 = 353$, which is the relative volume for $66\frac{1}{2}$ lbs. steam at the point of suppression. Tracing the expansion-curve EF for this pressure, as in the drawing, for which any number of intermediate points may be found in the same way, and drawing a horizontal

admission-line FG to the beginning of the stroke, the extra shaded area so enclosed is a representation of the real loss incurred by initial condensation of steam; and, without going into figures, it appears nearly as much again as the area, or power, actually obtained.

The diagrams just discussed, are, of course, extreme cases, which might occur in any cylinder, outside or inside; and they have been selected simply for purposes of illustration. They have served to shew in what way the expansion-curves of indicator diagrams may be turned to account in developing the condition of the steam. Our business is now to find to what extent, in the ordinary working of locomotives, the condition of the steam is affected by the circumstances of the cylinder.

It so happens, though not necessarily so, that inside cylinders are in general better protected than outside cylinders. The former are more completely within the smoke-box, and are more closely in contact with the smoke, and derive more benefit from its heat, than the latter; though, of course, there are many examples of inside cylinders being, for mechanical reasons, completely excluded from the smoke-box, and having no other advantage over outsides than that they are less exposed to atmospheric draughts. The distinction of outside and inside, occasionally employed in this paper, must be understood to refer, not to constructive arrangements, but to the incidental conditions of exposure and protection.

The stress of the argument will be derived chiefly from the results obtained from the well-protected cylinders of the "Great Britain," Great Western Railway, on the one hand, and the partially-protected cylinders of the Caledonian Railway passenger and goods engines, on the other, of which the passenger class, derived originally from the Crewe pattern, represent a widely-ramified species of outside-cylinder locomotive. Fig. 5, Plate 60, shows cross sections of the cylinders and smoke-boxes of the three classes of engines now referred to, in which it is apparent that the inside cylinder is the best protected.

The first point is to shew, by the expansion-line, that in well-protected cylinders the steam is not subject to condensation. Referring to the twenty-six indicator-diagrams from the "Great

Britain," of which specimens were given in the last paper, the following table, No. 7, contains, in col. 1, the initial and final volumes of the steam expanded, clearance included, measured in inches of the stroke; in cols. 3 and 4, the observed initial and final pressures; in cols. 5 and 6, the initial and final water-equivalents of the expanded steam, deduced in terms of the capacity of the cylinder, and the relative volumes of steam due to the pressures; col. 7 contains the differences of these equivalents. At the foot of the table are added the means for each notch.

It appears that for each notch the influence of speed on the relation of the initial and final water-equivalents of the steam expanded is nearly inappreciable. Dealing, therefore, with the means, it appears that the mean differences, col. 7, constitute,—

For the 1st notch, 3 per cent. of the initial equivalent.
,, 3rd ,, $5\frac{1}{2}$,, ,, ,,
,, 5th ,, $2\frac{1}{4}$,, ,, ,,

These per-centages are practically nothing, and the virtual constancy of the mass of expanding steam during expansion, thereby proved, shows that for the greatest observed degrees of expansion in the cylinder of the "Great Britain," no change in the condition of the steam is observable, and that there is, consequently, no condensation at all.

Experiments made by the writer on some of the engines of the Edinburgh and Glasgow Railway, with inside cylinders, lead to the same conclusion.

Of the numerous diagrams obtained from the outside-cylinder engines of the Caledonian Railway, seventy-six were selected by the writer as average samples of diagrams obtained by him during the regular work of the engines. These have been analysed in the way adopted for those of the "Great Britain," and the mean results for each engine are tabulated below, ranging from 9 per cent. deficiency, to as much as 67 per cent. excess at the greatest expansion. Specimens of the diagrams from No. 42, Passenger-engine, and from No. 125, Goods-engine, are given in Fig. 2, Plate 61. These diagrams were taken by McNaught's indicator, and the dotted lines show the actual curves which are affected by the oscillation, to which that indicator is subject at high velocities. The mean

TABLE No. 7.—*Of the Expansion and Water Equivalents of Steam in the Cylinder of the "Great Britain."*

Initial and Final Volumes by Expansion, in Inches of the Stroke, clearance included.	No. of Diagram.	Absolute Pressures during Expansion. Initial.	Final.	Equivalents of Water. Initial.	Final.	Difference.
		lbs.	lbs.	Cub. Ins.	Cub. Ins.	Cub. Ins.
	1	70	50	13·32	13·37	+0·05
FIRST NOTCH	2	88	65	15·89	16·16	+0·27
	3	94	65	16·71	16·16	—0·55
Cutting off 17·8 Ins.	4	84	57	15·30	14·65	—0·65
Exhaust ... 22·8 „	5	74	49	13·89	13·19	—0·70
	6	86	55	15·62	14·29	—1·33
Expansion 1 to 1·3	7	80	56	14·76	14·47	—0·29
	8	52	34	10·73	10·32	—0·41
	9	86	60	15·62	15·23	—0·39
	10	87	48	12·19	11·84	—0·35
THIRD NOTCH.	11	70	37	10·33	9·95	—0·38
	12	90	45	12·50	11·84	—0·66
Cutting off 13·8 Ins.	13	72	38	10·55	10·12	—0·43
	14	75	38	10·87	10·12	—0·75
Exhaust ... 20·8 „	15	79	38	11·33	10·12	—1·21
Expansion 1 to 1·5	16	65	33	9·78	9·24	—0·54
	17	55	28	8·65	8·35	—0·30
	18	72	37	10·54	9·95	—0·59
	19	89	33	7·90	8·30	+0·40
FIFTH NOTCH.	20	70	24	6·59	6·96	+0·37
	21	93	33	8·20	8·35	+0·15
Cutting off 8·8 Ins.	22	74	21	6·87	6·42	—0·45
Exhaust .. 18·8 „	23	80	22	7·29	6·58	—0·71
	24	63	17	6·08	5·76	—0·32
Expansion 1 to 2·14	25	55	15	5·52	5·43	—0·09
	26	65	16	6·24	5·60	—0·64
Mean of 1st Notch		79	54·66	14·65	14·21	—0·44
„ 3rd „		74	38·40	10·75	10·17	—0·58
„ 5th „		74	20·25	6·83	6·67	—0·16
1	2	3	4	5	6	7

TABLE No. 8.—*Of the Expansion and Water-Equivalents of Steam in the Outside-Cylinder Engines of the Caledonian Railway; abstracted from the Results of* 76 *Indicator-Diagrams, obtained in* 1850.

No. of Engine.	Cylinder.		No. of Notch.	Initial and Final Volumes by Expansion, clearance included, In Inches of Stroke.		Ratio of Initial and Final Volumes.	Observed Pressures during Expansion.		Equivalents of Water.			
	Diameter.	Stroke.		Initial.	Final.		Initial.	Final.	Initial.	Final.	Differences.	Ratio of Differences to Initial Equivalent.
	Ins.	Ins.	No.	Cub. Ins.	Cub. Ins.	Ratio.	lbs.	lbs.	Cub. Ins.	Cub. Ins.	Cub. Ins.	Per Cent.
No. 13	15	20	1	14·02	18·82	1·35	52	34	5·93	5·92	—0·01	— 0·2
" "			2	11·27	17·82	1·60	45	24	4·26	4·51	+0·25	+ 1·2
" 33	15	20	4	13·33	18·75	1 40	45	22	5·02	4·57	—0 45	— 9·0
" "			5	12·00	18·30	1·52	56	27	5·27	4·99	—0·28	— 5·3
" "			7	8·00	16·10	2·01	46	16½	3·12	3·38	+0·26	+ 8·3
" 41	15	20	1	15·50	19·60	1·26	36	24	5·07	5·00	—0 07	— 1·4
" "			2	14 20	18 60	1·31	26	16	3·84	3·82	—0·02	— 0·5
" 42	15	20	3	12·10	18·35	1·52	55	30	5·27	5·34	+0·07	+ 1·3
" "			4	10·10	17·10	1·70	49	22	4·06	4·16	+0·10	+ 2·4
" "			5	4·50	15·10	3·33	68	22	2·29	3·68	+1·39	+67·0
" 51	15	20	3	10·36	17·70	1·72	59	29	4·56	4·94	+0·38	+ 8·3
" "			4	7·10	15·50	2·20	50	20	2·91	3·63	+0·72	+25·0
" 125	17	24	2	18·80	23·80	1·27	33	20	7·48	7·20	—0 28	— 3·7
" "			3	14·90	23·00	1·54	48	26½	7·57	7·98	+0·41	+ 5·4
" "			4	10·20	22·10	2·16	37	13½	4·36	5·39	+1·03	+24·0
" 127	17	24	5	5·70	16·20	2·84	57	20	3·26	4·77	+1·51	+46·3
1	2	3	4	5	6	7	8	9	10	11	12	13

lines have been drawn on the diagrams on the principle which the writer has satisfied himself applies in the particular case of the indicator,—that action and reaction are equal, and that therefore the mean line, or radical form, ought to enclose the same collective area of diagram as the fluctuations in the lines actually described, due partially to momentum, cutting off at one place as much as it encloses at another.

From this it appears that for the greater ratios of expansion, the final equivalent of the steam is much above the initial, and the greater the ratio the greater is the per-centage of this excess, amounting to 67 per cent., with an expansion of $3\frac{1}{3}$ times. This relation is just what was found for the slow diagrams from No. 13, and there is no doubt the excess of steam, at the termination of the expansion, is due to the same cause, namely,—the condensation of the steam in the cylinder during admission, and during the first part of the expansion, and the subsequent re-evaporation of a portion of the precipitated steam. During the experiments there was at all times ocular demonstration of the existence of water in the cylinder, in the spray which escaped from it through the indicator, and *which was given off more abundantly the more expansively the steam was worked.*

To find the general rate at which the per-centage of condensation increases in these engines with the degree of expansion, the results obtained above may be referred, as ordinates, to a base-line representing the ratios of expansion. Let AB, Fig. 4, Plate 62, be a base-line divided to represent the total volumes by expansion in terms of the initial volumes; and from B draw the vertical scale to measure the relative per-centages of condensation. From A set off on the base-line the ratios of expansion, and for each ratio set off perpendicular distances by the vertical scale, equal to the respective per-centages of the differences of water-equivalents, col. 13, and define their extremities by points, setting off minus per-centages below the line, and plus per-centages above. The mean line CD, drawn through these points, is straight, and represents the mean rate at which the indicated condensation increases with the degree of expansion. It is found to meet the vertical from division 1, at 20 per cent. below, crosses the base-line at a volume of 1·53,

and terminates at E, the point due to an expanded volume of 3·4, and to a per-centage of 70, and would, if produced, meet the vertical from B, at $92\frac{1}{2}$ per cent. The straightness of the line implies that the indicated per-centage of condensation increases uniformly with the relative volume by expansion. For an expansion of 1·53 times, the per-centage of condensation, or indicated difference of equivalents, is nothing; and, generally, for expansions advancing by half-volumes, the per-centages are as follows :—

Expanded Volumes, the Initial Volume being = 1.	Indicated Per-centages of Condensation.
1·5	— $1\frac{1}{4}$
1·53	0
2	$17\frac{1}{2}$
2·5	$36\frac{1}{4}$
3	55
3·5	$73\frac{3}{4}$
4	$92\frac{1}{2}$

For every half-volume of expansion there is an increase of $18\frac{3}{4}$ per cent. of indicated condensation, and this becomes so serious, that for an expansion of four times, if this were practicable with ordinary valves and link-motions, there would be $92\frac{1}{2}$ per cent. of loss by condensation, or a loss of nearly one half of the total quantity of steam admitted.

For ready reference it is expedient to find the relative expansion and indicated condensation for different periods of admission, yielded by ordinary link-motions. The following table, No. 9, contains in col. 2 the total expanded volumes due by the nature of link-motion to the several periods of admission in col. 1, and col. 3 contains the relative indicated per-centages of condensation due to these expansions, measured from the diagram.

Though the losses shown in the 3rd column are great, the real losses must be still greater; because the restoration of condensed steam, by which the losses have been measured, cannot be entire. The indications, indeed, fail to show any loss at all, at 50 per cent., as the re-evaporation balances the condensation during expansion. For 75 per cent., the re-evaporation

TABLE No. 9.—*Of the Indicated Condensation of Steam in Outside Cylinders, during the Admission of the Steam.*

Period of Admission, in parts of the Stroke.	Total Volume by Expansion (the Initial Volume being = 1.)	Apparent Condensation, in parts of the Indicated Steam cut off.	Approximate Proportion of Steam Condensed.	
			In parts of the INDICATED Steam condensed.	In parts of the WHOLE Steam consumed, (including the Condensed Steam.)
Per Cent.	Times.	Per Cent.	Per Cent.	Per Cent.
75	1·22	—12·0	12	11
60	1·40	— 5·2	12	11
50	1·54	0·0	12	11
40	1·78	9·4	21	17
30	2·07	19·9	32	24
20	2·45	34·1	46	32
12	3·17	61·1	73	42
1	2	3	4	5

(if any) is so slight as to leave a deficit of 12 per cent., by condensation, during expansion, compared with what was indicated as cut off. Now, the whole tenor of the evidence shows, plainly, that the degree of condensation increases as the admission is shortened; and it may be safely inferred that as 12 per cent. is shown to be lost in full gear, there is, at least, 12 per cent. of loss for 50 per cent. of admission, cutting off at half-stroke. An approximate loss of 12 per cent. will, on this ground, be adopted for all admissions greater than half-stroke; and 12 per cent. will also be added to the indicated losses for shorter admissions, as an approximation to the real conditions.

The most direct test of the amount of loss from condensation of the steam during expansion, appears to be the mode adopted above, of comparing the water-equivalents, or the actual weights of the steam present in the cylinder, at the beginning and at the end of the expansion.

An exact conclusion as to the amount of *condensation during expansion* cannot be obtained from the *loss of area* in the indicator diagram. The dotted line EFG added to Fig. 1, is not the curve that

would actually have been described had there been *no condensation*, but such as *might* have been described by the quantity of steam which the final pressure, during expansion, proves to have been admitted. The loss, by condensation, *could not have been less* than shown by the shaded area, but was certainly greater in amount, for it appears that a portion of the steam admitted, and sometimes a considerable amount of it, is buried for ever, and is not resuscitated at all at the end of the expansion. This is proved by the great increase of back pressure that takes place when a high degree of expansion is used, from the lower temperature of the cylinder, as illustrated by the diagrams in Fig. 9, which must have been caused by the quantity of precipitated steam still remaining in the cylinder after expansion.

Col. 4 contains the approximate losses as revised in the way above described, in parts of the *indicated* steam admitted. Adding the *lost* steam admitted to that indicated, the sum expresses the *whole* steam admitted and expended; and col. 5 contains the per-centage of approximate loss, expressed in terms of the whole steam so used, which is a more convenient form for reference. From this column it appears that for 40 per cent. admission, 17 per cent., or one-sixth of the steam, is condensed; for 30 per cent., one-fourth; for 20 per cent., one-third; and for 12 per cent., or mid-gear, two-fifths, or not far from one-half.

It must be added that the foregoing deductions are based on steam-pressures under 60 lbs., generally about 50 lbs. during admission. For higher pressures, and admissions above half-stroke, the condensation is proportionally less, as will afterwards be shown.

Proof of the condensation of steam in outside cylinders, by comparison of the indicated consumption of steam with the measured consumption of water.—Arguments for condensation based upon the measured consumption of water must be received with caution, because in some cases an excess of water passes off as "priming," without ever being evaporated at all. In the following discussion, care will be taken to avoid this source of error.

TABLE No. 10.—*Abstract of the working of the Passenger Engine No. 42, C. R., with Express Train, August, 1850. Cylinder 15 × 20 inches, Wheel 6 feet.*

Stations, Intermediate Distances, and times of Steam on.	Notch under which the Engine was worked.	Miles run under each Notch, with steam on.	Average Indicated Pressures at [illegible], under each Notch.
	No.	Miles.	lbs.
(1.) Glasgow to Motherwell, 16 miles, steam on, 30 min.	2	$\frac{1}{2}$	47
	4	$5\frac{1}{2}$	36
	,,	$5\frac{1}{2}$	50
Average admission 45 per cent. of stroke.	,,	3	72
		$14\frac{1}{2}$	
(2.) Motherwell to Carstairs, $15\frac{1}{2}$ miles, steam on, $29\frac{1}{2}$ min.	3	10	69
	,,	$2\frac{1}{4}$	38
	4	2	50
Average admission 54 per cent.		$14\frac{1}{4}$	
(3.) Carstairs to Beattock, 34 miles, steam on, $38\frac{1}{4}$ min.	3	$9\frac{1}{2}$	50
	4	11	50
	,,	3	58
Average admission 50 per cent.		$23\frac{1}{2}$	
(4.) Beattock to Carlisle, $39\frac{1}{2}$ miles, steam on, $56\frac{1}{4}$ min. Average admission 40 per cent.	2	$\frac{1}{2}$	60
	3	3	60
	,,	$1\frac{1}{4}$	30
	4	$12\frac{3}{4}$	38
	,,	2	50
	,,	$1\frac{3}{4}$	33
	,,	$7\frac{1}{2}$	52
	5	$3\frac{1}{2}$	30
	,,	$6\frac{1}{2}$	56
		$38\frac{3}{4}$	

For the purpose of testing this comparison, the following experiment was tried by the author on the actual consumption of water by an outside cylinder express engine, No. 42, for a trip of 105 miles, from Glasgow to Carlisle, on the Caledonian Railway, with a train averaging $6\frac{1}{2}$ carriages; the time of the trip being 3 hours 22 minutes, including five stoppages.

Indicator-diagrams were taken from the cylinder at intervals of one or two miles, and the notch of the expansion gear observed for each diagram, and the points of the line where each change of notch was made. The results are shown in the accompanying Table, No. 10.

The several points of cutting off, expansion, and compression were accurately ascertained by means of the slow diagrams; from which were calculated the exact quantities and pressures of sensible steam actually consumed in each interval of the trip, and the water-equivalents for the several quantities of steam present in the cylinder; which, multiplied by the number of strokes of the two cylinders in each interval, gives the total quantity of water efficiently used as steam.

The following final results were thus obtained:—

		Water used as Sensible Steam.	Water Consumed as Measured.	Excess.
1	Glasgow to Motherwell	30·76 ft.	35·82 ft.	5·06 ft., or 14 per cent.
2	Motherwell to Carstairs	43·91 ,,	48·85 ,,	4·94 ,, or 10 do.
3	Carstairs to Beattock	57·28 ,,	67·74 ,,	10·46 ,, or $15\frac{1}{2}$ do.
4	Beattock to Carlisle	62·42 ,,	79·50 ,,	17·06 ,, or $21\frac{1}{2}$ do.
	Total, Glasgow to Carlisle	194·37 ft.	231·91 ft.	37·54 ft., or $16\frac{1}{4}$ per cent.

The examination of the indicator-diagrams in the manner employed before, by comparing the initial and final water-equivalents of the steam during expansion, shows that at least 13 per cent. of this loss of $16\frac{1}{4}$ per cent. was due to condensation, and it is probable that no appreciable proportion was due to priming; indeed the *least loss* was observed to take place with the least degree of expansion,

and when the consumption of steam from the boiler is going on at the *greatest rate*, as we find on referring to the per-centages of admission in the first column of Table 10; which is the reverse of the effect that would be observed if priming were a material cause.

Experiments made by the writer with other outside-cylinder engines, or *imperfectly protected* cylinders, corroborate the above deductions obtained from the performance of No 42; and they are still further corroborated by his experiments on inside *well-protected* cylinders, which show that in ordinary good condition there is no sensible excess of water of any importance, actually measured from the boiler, above what is estimated from the indicated steam passed through the cylinder. These results are also confirmed by the results of the trials of Mr. D Gooch, with the "Great Britain" and similar engines.

The increased *back pressure of exhaust* affords additional evidence of the presence of water in the cylinder. The back exhaust pressure is the consequence of the want of facilities for the timely discharge of the exhaust steam from the cylinder; and the impediments to its discharge are much increased by the presence of water amongst the steam, whether due to condensation or to priming. The presence of water is immediately made apparent by the increase in the back exhaust pressure, shown by the indicator-diagram, as the writer has on many occasions had an opportunity of observing. The *effects of priming* from foulness of the water in the boiler are shown in Fig. 3, Plate 62: A and B are indicator-diagrams taken from the well-protected cylinders of the "Orion," in which very little, if any condensation could be detected. The diagram A was taken *before*, and the diagram B after the boiler was blown off and supplied with clear water, both being taken at the same speed, and showing 7 lbs. back pressure caused by priming in the former case.

The diagrams C and D, Fig. 3, Plate 62, show that the *total quantity of water* from condensation is considerably greater, with the greater degrees of expansion, where a *smaller quantity of steam* is admitted, and consequently the loss is more seriously felt. These diagrams were taken from the outside-cylinder goods engine No 127, working at the same speed up and down an incline on the Caledonian Railway; the diagram C cutting off at two-thirds the

stroke, and the diagram D at one-sixth of the stroke. The latter, D, though it had the advantage of a much earlier exhaust, and only one-fourth of the quantity of steam to discharge, was affected with 10lbs. more back pressure than the former, C, when working in full gear. This great back pressure was maintained over a continued run of twenty miles, when of course the cylinders had got into their working heat for that degree of expansion; and the inference is that the steam was loaded with water of condensation, (proved also by the expansion-curve,) which was with difficulty expelled, and which only became proportionably less when the degree of expansion was diminished; and, consequently, the mass of steam increased that was to be cooled within the same superficies of cylinder.

That the *total mass of the steam* has much to do with the condensation is proved by the diagrams E and F, Fig. 3, Plate 62, taken under the same degree of expansion, and at the same speed, but with 75 and 20lbs. steam respectively admitted to the cylinder. In the latter diagram, F, the back exhaust pressure is 7lbs. greater than in the former diagram, E, although the total quantity of steam to be discharged was so much less. In the latter case, indeed, there was found to be an excess of 18 per cent. of the whole water used over the indicated steam expended, which was most probably altogether by condensation, as the rate of consumption was so moderate as to preclude any likelihood of priming.

Now here is a case where, in the same class of engines, the back exhaust pressure *increases* as the quantity of steam to be discharged *becomes less*, notwithstanding that the facility for exhaust increases at the same time. This is clearly a case of water in the cylinder, the quantity of which increases with the degree of expansion; and the water is as clearly a precipitation of steam by condensation. Also, though a full admission of steam at higher pressures may reduce the proportion of condensation, yet whenever expansive working is attempted by cutting off earlier, the heavy back pressure and the course of the expansion-line alike show that no pressure of steam, however high during the admission, can mitigate the evils of condensation in exposed cylinders.

Evidence from the proportions of the valve-gear.—The remarkable

inversion, just discussed, of our ordinary experience with well-protected cylinders, whereby the back pressure rises with the degree of expansion, leads to the necessity for more liberal proportions of valve gear for outside cylinders, to afford a more free exhaust. The writer has invariably found that of the three fixed elements affecting the exhaust, namely, the sectional area of steam port, the inside lead, and the area of blast orifice, (so long as the port is larger than the orifice,) it is the orifice alone which in well-protected cylinders rules the amount of exhaust back pressure; the wider the orifice the less the pressure, in the ratio of the 4th power of the diameter of the orifice, or the square of the area; whereas, in exposed cylinders, the back pressure, is ruled both by the orifice and by the inside lead; the greater the orifice, *and the greater the inside lead also*, the less is the pressure. This is an important distinction, because it shows that, as inside lead is equal to the sum of the lap and the outside lead, and is, in fact, regulated by the lap, the lap of the valve is a very important element in the designing of outside cylinders, though practically a matter of indifference in insides. Accordingly, it has been found that in Sharp's inside-cylinder engines, on the Edinburgh and Glasgow Railway, which have only a $\frac{5}{8}$th-inch lap,—probably the shortest lap in present practice for a 15-inch cylinder,—the exhaust is as perfect as in the Caledonian passenger-engines with $1\frac{1}{2}$-inch lap for the same cylinder. Further, in inside cylinders with clean boilers, it is practically a matter of indifference what amount of wear or slugger may have taken place in the valve-gear, so far as concerns the exhaust: in outsides, on the contrary, it is a very important object to maintain the gearing in the highest order, so as to keep up the inside lead, as the wear of the gearing directly reduces the lead, and thereby increases the back pressure. The Caledonian is perhaps the first line in this country on which the special advantage of long lap for outside cylinders was experienced. Nor need there be any apprehension of reducing the tractive power of an engine by increasing the lap, and thereby shortening the period of admission, because the same admission may be obtained by increasing the lead and the travel of valve in the same ratio with the lap; and, it may be added, this may be simply done in existing link-motions, by extending the link

beyond the eccentric-rod ends, and thereby increasing the range of the sliding blocks, and the maximum travel.

The formidable degree of condensation which accompanies high expansion in partially-protected cylinders, accounts for the opinion held by men of experience of the inutility, for economical objects, of cutting off the steam earlier than at half-stroke, for the proved advantage of expansive working in inside cylinders is neutralised in outsides by the condensation. Mr. Buddicom, of the Rouen Railway, led the way in the re-introduction of outside cylinders in this country; and to this day, he, and some of his followers, have adhered to the fixed gab-motion.

Conditions on which the expansive working of steam in locomotives may be carried out with efficiency and success.—The first condition is to perfectly protect the cylinders, and to maintain them at a *temperature at least as high as that of the steam admitted to them.* Simple non-conducting envelopes are not sufficient; external supplies of heat must be employed, and the application of a steam-jacket to the cylinder would be advantageous, when other sources of heat are not readily available. The writer tried an experiment with the "Orion," Edinburgh and Glasgow Railway, which has its cylinders suspended in the smoke-box, like the "Great Britain's," in which, by the use of partitions, the hot air from the tubes was directed entirely round the cylinders, previously to its emerging by the chimney; but he could not detect the slightest change in the performance of the engine, probably because the hot air was really very little hotter than the steam, and the closer contact made no difference. For cylinders already well protected, more thorough modifications would be required to make a sensible improvement. The steam should also be surcharged, previously to entering the cylinder, by passing over an extensive heating surface, deriving its heat from the atmosphere of the smoke-box, or, if necessary, from a hotter source.

The writer has lately been favoured with the results of experiments made by Mr. W. C. Hare, of Stonehouse, Devon, on a small engine, with cylinder $3\frac{1}{2} \times 8$ inch stroke, and a boiler having 9 feet of heating surface. He employed a special coil of 40 feet of half-inch

copper tube, having 5½ feet of inside surface, and heated by a circular row of very small gas jets. A small cock was fixed on the top of the boiler, close to the mouth of the steam-pipe, and by occasionally opening it when the engine was working, any priming, or even mere dampness of the steam, could be detected; and thus the experiments could be conducted with the assurance that the results were not affected by priming. When the steam was passed through this surcharging pipe, and was heated to 400° previously to its entering the cylinder, the consumption of water from the boiler was three gallons per hour; and when the communication with the surcharging pipe was cut off, and the steam led directly to the cylinder, the water used amounted to six gallons, or twice the other, while doing the same work, and involved a great increase of fuel consumed. To effect the economy here noted, from which something must be allowed for the consumption of gas, it appears that a surcharging surface equal to fully one-half of the heating surface has been necessary; and it is probable that for locomotives a considerable allowance must be made to produce a very decided change. The results of this experiment show that very much has yet to be done before the capabilities of the locomotives are fully developed.

As steam has been found so very sensitive to *exposure* on the one hand, and to *surcharging* on the other, it would probably be of advantage *to lead the hot smoke round the barrel of the boiler and the fire-box*, or the barrel only, *previously to its discharge by the chimney*. The barrel only would probably be enough to tell with good effect, and the hot air might be led either in a winding flue round the boiler, or, what would be better, led along the entire lower half towards the firebox, and returned along the entire upper half to the chimney. If *all* the hot air were found too much, only *a part* of it might be diverted by partitions, or otherwise, from the upper or lower tubes.

The second condition of successful expansive working in locomotives is the combination of a sufficiently high boiler pressure of steam, with suitable proportions of cylinder and driving wheel, to admit of highly expansive working consistent with the required duty of the engine. It is probable that 150 lbs. per inch is about

the highest pressure at which it is advisable to work a locomotive, consistent with the fair working and durability of its parts. The maximum pressure being settled, and it being assumed that the same pressure is to be maintained in the cylinder during admission, the degree of expansion to be adopted determines the capacity of the cylinder to develope the necessary average power. Long strokes are not advisable on the score of stability, at least for outside cylinders, and large diameters should rather be adopted; for the same reason, large wheels are preferable.

Thirdly, in the details of the mechanism, the cylinder should be arranged to have the shortest practicable steam-way; as, for short admissions, a long steam-way deducts very much from the efficiency of the steam. Such an arrangement would be greatly promoted by the introduction of balanced valves, or such as have provision for preventing the steam-pressure on the back of the valve; as, by being balanced, they could with facility be made large enough to embrace the whole length of the cylinder. The loads which ordinary valves are forced to carry on their backs are enormous; and though there is certainly no momentum in these loads to contend with, yet the friction of surfaces due to the loads is very great, even at the most moderate computation.

In this attempt at an elucidation of the action of steam in the locomotive engine, the writer has endeavoured to keep constantly in view, that the proper observation and registration of facts supply the only sure basis on which principles of practical utility can be founded; as, in the conduct of investigations affecting the material laws of nature, the inquiry must be tempered with that consideration for practical necessities which cannot be disregarded with impunity.

Mr. Buckle observed that the Paper appeared to be prepared with great care, and was a valuable collection of practical information.

Mr. Crampton inquired whether it was intended in the Paper that outside cylinders could not be effectually protected?

He was aware there was a strong opinion amongst engineers that outside cylinders could not be properly protected, but he considered there was no impossibility in it.

Mr. CLARK replied, it was only intended to be stated in the Paper, that the general effect in practice was, that outside cylinders were worse protected than inside cylinders, and they were generally very much exposed.

Mr. BUCKLE observed, that it was very important to have the cylinders of all engines well protected; this was particularly attended to in the Cornish engines, in which a casing nine or ten inches thick of non-conducting material was placed round the cylinders, besides a steam jacket. The proportion of expansion should be regulated by the kind of work to be done; pumping admitted of a great extent of expansion, the jolt and inequality of motion being of no consideration, but in grinding flour, spinning cotton, &c., a uniform motion was obtained by a moderate proportion of expansion, say from one-fifth to one-eighth, according to the work to be done; this arrangement, with ample passages to the cylinders to admit and exhaust the steam, produced a motion for machinery nearly equal in uniformity to a water-wheel.

Mr. CRAMPTON thought that enough attention had certainly not been paid to the condensation in the cylinders of locomotives at slow speed; he did not think it was of so much importance at high speeds. It was also particularly of importance in steamboat engines, where the question had not received so much attention as it deserved. He remembered an experiment which showed a remarkable effect of condensation: four condensing engines, of equal size, were working coupled together in a boat, with the steam cut off at one-quarter of the stroke and expanded; two of the engines were then disconnected, and the other two engines were worked, cutting off at half stroke, using, consequently, the same quantity of steam as the four engines did, cutting off at one-quarter of the stroke; but a greater effect was found to be produced by the steam than when it was used

in the four cylinders. This increase of effect appeared to be entirely due to the greater amount of condensation that took place in the four cylinders than in the two cylinders. There were no steam jackets, only ordinary clothing on the cylinders, and he thought much improvement was required in this respect in marine engines, and it was a matter well deserving the consideration of engineers.

In reply to an inquiry, he said the boilers were working with salt water, but he did not think that would affect the result.

Mr. Clark said he had found that even at the highest speeds in locomotives there was great condensation with high degrees of expansion, except in the case of well-protected inside cylinders.

Mr. Peacock suggested, that part of the effect in the experiment mentioned by Mr. Crampton might have been due to the smaller amount of friction in the two cylinders than in the four cylinders, when giving out the same total amount of power.

Mr. Crampton replied, that a greater effect was found to be produced after allowance was made for the friction, by taking indicator-diagrams, and the relative consumption of the water.

Mr. Whytehead thought the loss by back pressure would also be less in the case of the two cylinders than with the four.

Mr. Bovill enquired whether Mr. Crampton could give the result of any trials of the relative consumption of steam, with unprotected cylinders, and with steam jackets?

Mr. Crampton replied that he could not give the exact comparison.

Mr. E. A. Cowper exhibited an indicator-diagram, which he had obtained from a 35-horse-power stationary engine, cutting off at about $\frac{1}{4}$-stroke, and working expansively, on which he had drawn the true expansion curve, according to Pambour; the difference between the actual and the theoretical curve was a confirmation of Mr. Clark's observations, the actual curve having fallen below the theoretical at the commencement, and gradually risen a little above it at the latter part of the expan-

sion, from the temperature of the cylinder being higher at that time than the steam. The engine had an uncovered cylinder without a steam jacket, but was not exposed to the cooling action of passing rapidly through the air like a locomotive cylinder. He observed, that Mr. Stephenson had mentioned at the last meeting an experiment by Mr. Trevithick, in which he had found that one bushel of coal burnt under the cylinder did as much duty as five bushels of coal burnt under the boiler, showing the economy of keeping the cylinder warm.

A vote of thanks was then passed to Mr. Clark for his paper.

The following Paper, by Mr. CHARLES W. SIEMENS, of London, was then read :—

ON THE EXPANSION OF ISOLATED STEAM, AND THE TOTAL HEAT OF STEAM.

The object of this Paper is to lay before the Members the results of certain experiments on Steam, purporting, in the first place, to corroborate Regnault's disproval of Watt's law, "that the sum of latent and sensible heat in steam of various pressures is the same," in the second place, to prove the rate of expansion by heat of Isolated Steam: and, in the third place, to illustrate the immediate practical results of those experiments in working Steam Engines expansively.

The Author pursued these experiments at long intervals since the year 1847, with no other object in view than to extend his own information; and, consequently, without pretence to generalisation or extreme accuracy. The question, however, is one of great practical importance to Engineers, and with the advantage of valuable suggestions and the co-operation of his friends, Mr. Edward A. Cowper and Mr. William P. Marshall, the Author has again taken up the experiments, which, having been referred to at the previous meeting by Mr. Cowper, he feels himself called upon to lay before this institution in their present state, though incomplete.

The amount of heat required to convert one pound of Water into Steam of different pressures has occupied the attention of Natural Philosophers from the earliest periods of the modern Steam Engine.

Dr. Black observed, about a century ago, that a large quantity of heat was absorbed by water in its conversion into Steam (not accompanied by an increase of temperature), which he termed "the Latent heat of Steam." His apparatus consisted simply of a metallic vessel containing water, which he exposed to a very regular fire; and from the comparative time which was occupied, first in raising the temperature of the water to the boiling point, and, secondly, in effecting the evaporation, he approximately determined the *amount* of latent heat. Resuming the experiment, in conjunction with Dr. Irvine, he employed a different apparatus, consisting of a Steam Generator, and of a Surface Condenser, or a Serpentine Tube, surrounded by a large body of cold water.

The Steam which condensed in the Serpentine Tube was carefully collected and weighed, and the rise of temperature of the surrounding water was observed, which, multiplied by its known quantity, represented the total quantity of heat which the Steam had yielded.

The quantity of heat requisite to raise the temperature of one pound of water through 1° Fahr. being taken for the unit of heat, Black and Irvine obtained for the total quantity of heat in

Steam of atmospheric pressure, the number ...	954
Southern	1021
Watt obtained the number	1140
Regnault	1145
Dr. Ure	1147
Desprer, 1136, but later	1152
Brix	1152
Gay Lussac and Clement	1170
Count Rumford...	1206

All of these eminent Experimentalists employed essentially the same apparatus, and the differences between their results proves its

great liability to error. Brix, of Berlin, was the first to investigate these errors, and to calculate approximately their effect upon the results obtained.

While such a large amount of labour and talent has been expended to determine the latent heat in Steam of atmospheric pressure, a far more important question seems to have been passed over with neglect, namely, What is the relative amount of heat in Steam of various densities?

The celebrated Watt justly perceived the importance of this question, but contented himself with one experiment upon which he based his law, "*that the sum of latent and sensible heat in Steam is the same under all pressures.*"

Southern repeated the experiment, and found that Steam of greater density contained absolutely more heat than Steam of lower pressure, which induced him to adopt the hypothesis that "*the latent heat of Steam was the same at all pressures.*"

Subsequent experiments and general reasoning seemed to be in favour of Watt's law, which enjoyed the general confidence until it was attacked, only a few years since, by Regnault, of Paris, who proved by a series of exceedingly elaborate and carefully conducted experiments, that neither the law of Watt nor that of Southern was correct, but that the truth lay between the two. The apparatus employed by M. Regnault may be said to be a refinement upon those previously employed, and with the advantage of Brix's labours to determine the amount of errors, he seems to have succeeded in measuring the absolute amount of heat in Steam of various pressures with surprising accuracy.

The costly and complicated nature of the apparatus employed by M. Regnault, has hitherto prevented other experimentalists from repeating the experiment, and in the meantime practical engineers still continue to adhere to Watt's law.

Shortly after the publication of Regnault's experiments by the Cavendish Society, in 1848, the idea occurred to the Author of the present paper that their results might be brought to a positive test by a simple apparatus, which he places before the meeting in operation, shown in Fig. 1, Plate 63. It consists of an upright

cylindrical vessel of tin-plate A, which is surrounded by an outer vessel filled with charcoal BB, or other non-conducting material. A Steam-pipe C, with a contracted glass vein D, enters the inner vessel in a slanting position, in order that the water of priming from the boiler, and of condensation within the pipe, may return to the former, allowing only a small jet of pure steam to enter the vessel, where it suddenly expands and communicates its temperature to the bulb of a thermometer E, which is inserted through a stuffing-box from above. The lower extremity of the inner vessel A is connected on the one hand to a mercury gauge G, and on the other to a condenser, by means of a stop-cock to regulate the pressure. The pressure and temperature of the Steam within the boiler being known, and the temperature of the expanded steam observed, it will be seen whether that temperature coincides with the temperature which is due to pressure indicated by the mercury gauge. If it did, then Watt's law would be confirmed, but since the temperature rises higher than is due to the pressure, it follows that the high-pressure Steam contains an excess of heat, which serves to *super-heat* the expanded Steam. All losses of heat from the apparatus would tend to reduce the temperature, and be in favour of Watt's law; but it will be shown that those losses may be entirely eliminated, and a true quantitative result be obtained. For this purpose the pressure in the boiler should first be raised to its highest point, and the indicating apparatus be well penetrated by the heat; the fire under the boiler should thereupon be reduced, and observations made simultaneously, and at regular intervals, of the declining pressure within the boiler, and temperature of the expanded Steam of constant pressure. The pressures being nearly equal, the fire under the boiler is again increased, and the observations continued until the maximum pressure is once more obtained; and the loss of heat by radiation, &c., may be correctly estimated, by a comparison of the two series of observations.

The second portion of this paper relates to the rate of expansion of Isolated Steam by heat, that is, steam isolated from the water from which it is generated.

The Author has not been able to meet with any direct experiments on this subject, except some at a recent period by Mr. Frost, of America, which, however, do not seem entitled to much confidence. The rate of expansion of air and other permanent gases by heat was first determined by Dalton and Gay Lussac simultaneously, who determined that all gases expanded uniformly, and at the same absolute rate, amounting to an increase of bulk equal to $\frac{1}{480}$th part of the total bulk at 32° Fahr. for every one degree Fahr., or $\frac{1}{660}$th part of the total bulk at 212°. Dulong and Petit confirmed the law of Dalton and Gay Lussac, but it appears that these philosophers confined their labours to the permanent gases and atmospheric pressure, and merely supposed the general applicability of their discovery.

Being interested in the application of "super-heated" Steam, the Author tried some direct experiments on its rate of expansion, in the year 1847, which confirmed his view, that vapours expand more rapidly than permanent gases, or in other words, *that the rate of expansion of different gases and vapours is equal, not at the same absolute temperature, but at points equally removed from their points of generation.*

The apparatus employed in these experiments has been placed before the meeting, and its simplicity, when seen in operation, is such that the result, it is hoped, can hardly be doubted.

It is shown in Fig. 2, Plate 63, and consists of a metallic trough AA, containing oil, which is placed upon a furnace BB, heated by gas flames. One end of the trough is provided with a stuffing-box, through which a glass tube C, of about $\frac{1}{10}$th inch diameter, and sealed at one end, may be slipped, which will rest horizontally upon a scale below the surface of the oil. The mouth of the glass tube is connected to an open mercury syphon G, with either the one or the other leg filled with mercury, to produce the desired pressure within the horizontal glass tube. A small drop of water and a piston of mercury P being introduced into the bottom of the tube, it is placed in the oil bath, and connected to the syphon. The oil bath is then gradually heated, and the temperature observed. As soon as the boiling point of water under the pressure in question is reached, the mercury piston will move rapidly

forward, until all the water is converted into steam. The temperature continuing to increase, the piston will continue its course more slowly upon the scale, where its progress is noted from time to time, together with the temperature.

The experiment is continued until the temperature reaches about 400°, when the oil begins to boil. The gas flame is then withdrawn, and the bath allowed to cool gradually. The observations of the temperature and the position of the mercury piston are continued until the Steam contained behind it is recondensed. A comparison between the two series of observations gives the correct mean of the experiment, by which the effects of the friction of the mercury piston, any possible slight leakage of Steam past it, and faults consequent on the slow transmission of heat, are completely neutralized.

The curve A on Fig. 3, Plate 64, has been drawn, expressing the rate of expansion of atmospheric Steam according to these experiments. The results of nine separate experiments very nearly coincide, (as shown by the dotted lines, which give the extreme variation in the experiments,) except at the starting point, where the rate of expansion is so very great that it is difficult to obtain correct observations; changes in the barometer, moreover, affect the curve in the vicinity of the boiling point. To obviate the effect of these inaccuracies, the unit of volume in laying down the curves from each of the nine experiments was taken, not at the absolute boiling point, but at 250°, where the expansion had already assumed a definite course.

The diagram also shows a *straight line* B, expressing the rate of expansion of common Air, which at first diverges greatly from the hyperbolic curve of expansion of steam, although the assymptote of the latter seems to run parallel to the former. The Author considers it therefore highly probable, "*that the rate of expansion of all gases may be expressed by one hyperbola, which starts from the condensing point of the gas,*" and that the apparently uniform rate of expansion of the permanent gases may be accounted for by their great elevation, at the ordinary temperature, above their supposed boiling point, in consequence whereof the true curve approaches so nearly to its assymptote that the difference cannot be detected by experiments.

The general result obtained from the above experiments may be stated as follows:—that Steam generated at 212°, and maintained at a constant pressure of one atmosphere, when heated out of contact with water to

230°	is expanded	5 times	more than Air	would be.
240°	ditto	4	ditto	ditto
260°	ditto	3	ditto	ditto.
370°	ditto	2	ditto	ditto

The Author intends to extend the range of his experiments upon gases and vapours under high pressure, and will be glad to communicate the further results to the Institution.

The diagram contains another curve, C, showing the results of Mr. Frost's experiments, alluded to before, which, from the very sudden and irregular rise at the commencement, appears to be affected by some serious source of error.

The two curves of *pressure* and *density*, P and D, show the rate at which *saturated Steam* increases in pressure and in density, with the rise of temperature marked at the bottom of the diagram. It will be observed that the pressure increases at a rather greater rate than the density; and it is a remarkable circumstance, that the difference, or the rate at which the pressure increases faster than the density, which is in effect the rate of *expansion of saturated Steam* with the increase of sensible temperature, *exactly coincides* with the line B, representing the rate of expansion of Atmospheric Air.

An extension of our knowledge on the properties of Steam is a matter of such evident importance to Engineers, that it would be useless to dwell upon its practical importance. Suffice it to say, that it has been theoretically demonstrated that a perfect Boulton and Watt Condensing Engine (abstracting friction and all losses of heat in the furnace and through radiation) would only yield about seven per cent. of the mechanical force which would be equivalent to the expanded heat. It may be argued from this, that the Steam Engine is destined to undergo another great modification in principle, and in the Author's humble opinion this crisis will be

accelerated by inquiries into those properties of gaseous fluids which have hitherto excited but little attention, and especially into the properties of Dry Steam, or Isolated Steam.

The present Paper will be confined to showing the effect of the above experiments upon the rate of Expansion of Steam within the Steam Cylinder of an Engine. It was demonstrated by the first-named experiments, that *Expanded Steam is Super-heated Steam;* and, by the second, it is shown what is the expansion of bulk due to an increase of temperature.

Supposing the results of the experiments to be correct, the expansion curve as laid down by Pambour, and which is based upon Watt's law, requires a modification due to the excess of temperature in Expanded Steam; and it will be observed that this correction in the curve of expansion is in favour of working engines expansively, as a greater average pressure is obtained during expansion than would be the case if the expanded steam were not thus super-heated. Its correctness is corroborated by some actual observations by Mr. Edward A. Cowper in taking diagrams of expansive engines, previous to his acquaintance with the above experiments. It moreover appears that in Cornwall, Engineers have been practically acquainted with the fact, that Expanded Steam is Super-heated Steam, and more economic in its use than Saturated Steam; for it is a practice with them to generate the Steam at very high pressure, and to expand it down to the required pressure previous to its reaching the Steam Cylinder.

Another remarkable practical observation is, that a jet of high-pressure Steam does not scald the naked hand, while a jet of low-pressure Steam does, although the high-pressure Steam is the hotter substance. The cooling effect of a jet of high-pressure Steam is so powerful, that, as the Author has been informed, ice has been actually produced in the heat of summer in America, by blowing a powerful jet of Steam of 400 lbs. pressure per square inch against a damp cloth. This phenomenon may be explained by the perfectly dry and under-saturated state of Expanded Steam, which, with a strong tendency to re-saturate itself, produces a powerful evaporation on moist surfaces with which it comes in contact.

The rapid rate of Expansion of Steam by heat, when still near

Table of Experiments on the Expansion of Isolated Atmospheric Steam.

Temperature Fahrenheit Degrees	1 Ascending	2 Descending	3 Descending	4 Ascending	5 Descending	6 Ascending	7 Descending	8 Ascending	9 Descending
209	[illegible]	...	...	...	...	...	...	...	...
210	8·00	...	...	...	...	...	...	...	...
212	8·00	8·00	...	10·00	9·70	...	8·00	...	9·04
213	...	...	10·00	...	...	...	...	...	...
214	...	8·40	10·40	...	10·05	...	9·60	...	...
215	8·80	8·68	10·52	10·12	10·16	...	9·80	...	9·30
217½	9·00	8·90	10·66	10·20	10·32	...	...	9·31	9·45
220	9·10	9·11	10·84	10·30	10·50	...	10·50	9·50	9·57
222½	9·22	...	10·94	10·48	10·61	...	...	9·60	9·65
225	9·32	9·34	11·01	10·53	10·70	...	10·70	9·68	9·74
227½	...	...	11·11	10·60	...	...	...	9·78	...
230	9·54	9·58	11·21	10·68	10·86	...	11·00	9·81	9·91
232½	...	...	11·29	...	...	...	...	...	...
235	9·68	9·70	11·34	10·84	11·00	...	11·16	9·95	10·02
240	9·80	9·85	11·46	10·94	11·12	...	11·34	10·06	10·13
245	9·94	9·96	11·58	11·04	11·23	...	11·49	10·19	10·23
250	10·10	10·05	11·70	11·18	11·35	...	11·60	10·29	10·34
255	10·21	10·15	11·80	11·30	11·47	...	11·71	10·40	10·44
260	10·31	10·25	11·90	11·40	11·59	...	11·83	10·50	10·54
261	...	...	...	...	...	11·90	...	...	...
265	10·41	10·35	12·00	11·51	11·70	...	11·94	10·60	10·64
268	...	...	...	...	...	12·10	...	...	...
270	10·51	10·44	...	11·61	11·80	12·18	12·08	10·70	10·75
275	10·60	10·53	...	11·73	11·91	...	12·16	10·80	10·85
278	...	...	...	...	...	12·30	...	...	...
280	10·70	10·62	...	11·85	12·02	12·35	12·28	10·90	10·96
284	...	...	...	...	...	12·45	...	...	...
285	10·80	10·72	...	11·98	12·14	...	12·40	11·00	11·06
290	10·90	10·81	...	12·10	12·26	12·55	12·50	11·10	11·17
294	...	...	...	...	...	12·64	...	...	...
295	10·98	10·91	...	12·20	12·39	...	12·60	11·20	11·27
298	...	...	...	...	...	12·75	...	...	...
300	11·08	11·01	...	12·30	12·50	12·79	12·70	11·30	11·38
305	11·18	11·11	...	12·40	12·58	12·88	12·80	11·40	11·48
310	11·26	11·21	...	12·51	12·69	13·00	12·95	11·50	11·58
315	11·36	11·31	...	12·62	12·80	13·10	13·08	11·60	11·69
320	11·46	11·42	...	12·73	12·90	...	...	11·71	11·79
325	11·56	11·52	...	12·85	13·02	...	...	11·81	11·89
330	11·63	11·64	...	12·98	13·15	...	...	11·91	11·99
335	11·73	11·75	...	13·10	13·25	...	...	12·02	12·08
340	11·83	11·85	...	13·21	13·36	...	...	...	...
345	11·93	11·95	...	13·33	13·41	...	...	...	...
350	12·02	12·05	...	13·48	13·50	...	...	...	...
355	12·11	12·15	...	...	...	...	...	...	...
360	12·20	12·26	...	...	...	...	...	...	...
365	12·30	12·40	...	...	...	...	...	...	...
370	12·40	12·50	...	...	...	...	...	...	...
375	12·50	12·55	...	...	...	...	...	...	...
380	12·60	12·60	...	...	...	...	...	...	...

its boiling point, proves the economy of heating the Steam Cylinder either by a Steam jacket, or by the application of fire. It is, however, important to observe, that the specific heat of Steam seems to diminish, the more the temperature exceeds the boiling point. The annexed table of observations gives the data from which the curve A in Fig. 3 has been drawn.

Mr. Siemens explained the action of the two instruments, and showed their process in operation.

Mr. Crampton enquired whether the charcoal in the casing of the instrument would not get heated by the tube of high-pressure steam passing through it during the experiment, and so super-heat the steam in the internal cylinder?

Mr. Siemens explained, that it was not possible for such an effect to take place, as the end of the steam-pipe was exceedingly small, and was protected by a thick non-conducting casing. He had also observed several times during the experiments, that whenever any priming took place in the boiler, and a drop of water came out with the steam, and fell on the bulb of the internal thermometer, the mercury fell immediately to 212°, or the boiling point of water, and remained steadily there for four or five minutes, until the whole of the priming water was converted into steam, when the mercury again gradually rose to its former temperature. This showed that the increased temperature above 212° in the internal cylinder was entirely due to the extra heat in the expanded high-pressure steam, and not to any heat derived from the charcoal casing.

Mr. Crampton remarked, that from the larger proportion of the steam-tube shown in the sketch, it had appeared to him that heat would be communicated to the casing; but from the explanation given, and the manner in which Mr. Siemens conducted his experiments, he had no doubt of the good results obtained.

Mr. E. A. Cowper observed, that the only source of heat to raise the temperature of the charcoal casing, was the super-heat

in the expanded steam in the interior of the cylinder, as the jet of high-pressure steam was so small and well protected, that it could not have any appreciable effect in heating the charcoal. Consequently, the charcoal casing could only attain the temperature of the expanded steam that was passing through it, and could not influence the temperature of that steam. In the first experiments tried by Mr. Siemens and himself, the lower end of the cylinder was entirely open to the atmosphere, so as to try the experiment with steam expanded down to the atmospheric pressure; and as the expanded steam was passing out into the atmosphere in a constant stream from the open mouth of the cylinder, it was impossible there that the increased temperature maintained in the cylinder could have been affected by the charcoal casing, and it could only have been due to the extra heat contained in the high-pressure steam.

Mr. Siemens said, that as a check on the accuracy of the observations, he had tried them successively in an ascending and a descending series, when any error from the source alluded to would have been made apparent, and been doubled in effect, but he could not detect more than one degree difference in the observations.

The thanks of the meeting were voted to Mr. Siemens for his paper and experiments.

The following paper, by Mr. Charles Cowper, of London, was then read:—

ON BOURDON'S METALLIC BAROMETER, INDICATOR, AND OTHER APPLICATIONS OF THE SAME PRINCIPLE.

Various instruments have been invented and employed for Measuring the Pressure of the Atmosphere, and also for Measuring the Pressure of Steam and other Fluids, but they may be divided into three principal classes.

In the first of these, the pressure is ascertained by measuring the height of the column of mercury which it is capable of sustaining, as in the common Barometer and the ordinary Mercurial Pressure-gauge.

In the second class, the pressure of the air or other fluid is ascertained by the amount of compression which it is capable of producing in a portion of air confined in a bent tube or syphon, by a portion of mercury or other liquid. The Sympiesometer and the Short Mercurial Steam Gauge are constructed on this principle.

The third class consists of a cylinder and piston, the piston being attached to a spring; Watt's Indicator is constructed on this principle, and it has also been proposed to employ it as a Barometer, by exhausting the air from the interior.

The difficulty of obtaining an air-tight piston, sufficiently free from friction, appears to have led M. Conté, at the latter end of the last century, to propose the application of a shallow air-tight box, covered with a thin metallic diaphragm, and exhausted of air. The diaphragm was supported by springs contained within the box, so that it rose and fell with the variations in the pressure of the atmosphere. The instrument known as the Aneroid Barometer is constructed in a similar manner, and the small motion of the diaphragm is greatly multiplied by means of levers. A similar instrument was constructed by M. Bourdon, as long since as the year 1843, for the purpose of a steam gauge. After many experiments, however, he laid it aside, as he found that the metal cracked after a continued use, and rendered the instrument useless.

The invention of the Instruments which are the subject of the present Paper, was the result of a careful observation of an accidental circumstance. M. Bourdon had occasion to restore the form of a worm-pipe of a still, which had been accidentally flattened. To effect this, he closed one end and forced water in it at the other end. The flattened tube expanded to its proper form, but at the same time M. Bourdon observed that the tube uncoiled itself to a certain extent, and it occurred to him to apply this fact to the construction of a Pressure-gauge. He did so, and with perfect success.

The principle of the Instruments will be best explained by the aid of the accompanying diagrams, Plate 6A.

Fig. 1 is a section, and Fig. 2 a front view of a flattened metallic tube, bent into a circular form. If a pressure of steam or other fluid be applied to the interior of this tube, it will be found to uncoil itself as the pressure increases until it assumes the form shown in Fig. 3, and on removing the pressure it will return to its original form. If it is exposed to external pressure, or if the air is withdrawn from the interior, the tube coils itself up to a smaller diameter, as shown in Fig. 4. It will be found that as the tube uncoils itself it becomes thicker, from the sides becoming more convex, and as it coils itself up it becomes thinner. It is upon this relation between the thickness of the tube and the diameter of the coil, that the action of the instrument depends.

If a flat band of metal is bent round into a circle, its transverse form remains unaltered, but if a semi-cylindrical, or gutter-shaped band, like that shown at A, in Fig. 5, is bent into a circular form, its convexity is diminished, as shown at B, and if the circle to which it is bent is of small diameter, the band will become almost flat in the transverse direction.

The same effect takes place with a complete tube as with the gutter-shaped band, and it is owing to this peculiarity that tubular bodies possess such great rigidity. In fact, it is a law of general application, that a surface which is curved in two directions cannot have its curvature increased in one direction without diminishing its curvature in the other direction, and *vice versa*.

A tube may be considered as an assemblage of separate parallel filaments or wires, and if a curved gutter-shaped assemblage of wires, as shown in Fig. 6, is flattened out, it assumes the form shown in plan in Fig. 7, from the central wires being longer than those at the sides, owing to their having originally formed a portion of a larger circle. If on the other hand the gutter be curved to a smaller diameter, the ends will become hollow instead of round. As these effects cannot take place in a gutter-shaped band formed of one piece of metal, it becomes necessary for the different parts to accommodate themselves to the varying curvature in some other manner. This is effected by the change

in the thickness of the tube, which allows the two sides to assume a greater degree of convexity in the transverse direction, in proportion to the diminution of their curvature in the longitudinal direction.

The converse of this proposition equally holds good, that is to say, if pressure is applied to the interior of a curved tube B of a flattened section similar to that shown in Fig. 8, the effect is to separate the two sides of the tube in the direction of the line AC, and thus to increase their convexity in the transverse direction, as shown at D. The consequence is the diminution of their curvature in the longitudinal direction, as shown at E.

From these considerations it follows that a curved tube of cylindrical or circular section will not experience any change of curvature, when submitted to internal pressure, as the circle is the sectional form which all tubes tend to assume when exposed to internal pressure. As the sectional form therefore cannot alter, the longitudinal curvature ought also to remain unchanged. This theoretical observation is confirmed by actual experiment, the curved tube of circular section remaining unaltered in form when submitted to internal pressure. The result is the same with external pressure, provided of course that the pressure is insufficient to totally collapse and destroy the tube.

The mutual dependance of the two curvatures on one another is also proved in the following manner. When the flattened tube is embraced by a series of separate small clamps, of the form shown in Fig. 9, so as to prevent its sectional form from altering on the application of internal pressure, the consequence is that its longitudinal curvature also remains unchanged.

On the other hand, when the two ends of the tube are joined so as to complete the circle, and the pressure is then applied, the consequence is that the tube, being unable to alter its longitudinal curvature, remains also unaltered in thickness.

The variation in the thickness of a curved flattened tube with variations of curvature is proved by actual measurement.

This variation is proportional to the change in its curvature, and *vice versa*. Thus, in Fig. 10, ABCD represents a curved

flattened tube, the arc AB having a radius of 60 parts, and the arc CD having a radius of 50 parts, the interval AC or the thickness of the tube being 10. If the arc AB is brought closer to CD by the application of external pressure, the arc AB will necessarily be too long for its new position. To establish the proper relation between the two arcs, their respective radii must still maintain their original relative proportion, or in other words, if the distance AC is reduced to eight parts or diminished one fifth, the radii must also be diminished one fifth each, and reduced to forty-eight and forty parts respectively. The length of the arc remaining constant, while the diameter is reduced, the radii will necessarily form an angle one fourth larger that in the original position, that is to say, if the original angle was sixty degrees, it will now be increased to seventy-five degrees. In Fig. 11 the dark lines show the original form, and the dotted lines show the effect produced by approaching the two arcs together. Fig. 12 shows the new form acquired by the tube.

The change in thickness of the tube is thus proportioned to the variation of its radius of curvature, and it is found by experiment that the motion of the extremities of the tube is proportional to the pressure applied, so that the indications are equal for equal increments of pressure.

This fact is of considerable importance, as it greatly facilitates the application of the principle to the construction of pressure-gauges, barometers, and other instruments.

The simplest form of these instruments is the Steam Pressure-gauge, Figs. 16 and 17, Plate 66, in which rather more than one convolution of flattened tube AA is employed. One end of this tube is fixed to a stop-cock B, in connection with the steam boiler, and the other end carries an index C, the extremity of which traverses over a scale graduated to pounds pressure per square inch. In some cases a small slider or an additional loose hand is added, which is pushed forward by the motion of the index, and serves to register the maximum or minimum pressure.

In another form of the instrument, the flattened tube is fixed at the top, and makes one turn, and the free end is connected by

a link to a lever and index. These instruments serve equally well as pressure-gauges and as vacuum-gauges. The dimensions of the tube and scale are varied according to the pressure to which they are to be exposed, and the degree of delicacy required in the indications.

This instrument answers perfectly for fixed engines, but if its position is varied by laying it on its side, the weight of the tube causes it to spring a little, and thus to interfere with the accuracy of its indications. Therefore, in cases in which the position of the instrument is exposed to variation, as in seagoing vessels, it is preferable to employ a circular tube fixed in the centre to the stop-cock, and having its ends connected by links to the two ends of a lever, turning upon a centre, and carrying the index. The two branches of the tube are thus made to balance each other, and the index being also balanced, the instrument may be placed in any position without its indications being thereby affected.

When a great range of motion is required, the lever is not placed on the axis of the index, but carries a toothed segment which drives a pinion on the spindle of the index.

Figs. 18 and 19 show a Pressure-gauge constructed in this manner. The bent tube AA is fixed in the centre, and the two branches of the tube are made to balance each other. The lever B to which they are connected gives motion to a toothed sector C, which is also balanced, and which drives a pinion on the axis of the index D, which is balanced.

This arrangement is well adapted for Barometers, in which case the air is exhausted from the flattened tube, which is then soldered up. The pressure of the atmosphere acts on the exterior, and is balanced by the elasticity of the tube, which varies in curvature with every variation in the pressure of the atmosphere. In order to prevent any slackness in the different joints from affecting the accuracy of the indication, a small hair-spring may be attached to the axis of the index, which will keep a slight tension upon all the joints, and keep the teeth of the pinion always in gear with the same side of the teeth of the sector. The Barometers are constructed with broader and thinner tubes than the steam pressure-gauges, as the variations of pressure to which they are subjected

being comparatively small, it is desirable to obtain a considerable motion with these small variations of pressure.

Fig. 13, Plate 65, is the section of tube which is generally employed for Barometers, while Figs. 14 and 15 are generally employed for steam pressure-gauges.

In order to give some idea of the extent of motion which is readily obtainable in these instruments, the following experiment may be mentioned. A tube of the sectional form shown in Fig. 13, and about three inches wide, was bent into a circle of about ten inches diameter. One end of the tube was closed, and a small tube attached to the other extremity. By placing this tube to the mouth, and blowing into the tube, it was caused to expand, and by sucking out the air the tube was made to contract. The motion thus produced in the free end of the tube was fully three inches. In the Barometers in which a tube about one inch wide is bent into a circle of about four inches diameter, the motion caused by exhausting the air from the tube is about an inch, but varies according to the sectional form and thickness of the metal which forms the tube.

If the curved flattened tube be filled with alcohol or other liquid, and hermetically closed, the instrument becomes a Thermometer, showing by the motion of the index, every change in the volume of the enclosed liquid. The tube, being formed of metal, has the advantage of transmitting the heat to the enclosed liquid with greater rapidity than is the case with a glass Thermometer. In some cases, however, as in ascertaining the temperature of corrosive liquids, it might be advisable to employ a tube of glass.

A Pyrometer, for measuring high temperature, is made by connecting one of the pressure-gauges by a small platinum tube to a hollow ball of platinum, filled with air. The platinum ball being exposed to heat, the elasticity of the air contained in it is increased, and its pressure is indicated by the pressure-gauge.

If in place of *bending* the flattened tube, it is *twisted*, by fixing one end and turning the other round, a sort of quick threaded screw is obtained, which has the property of untwisting itself when acted on by internal pressure, and *vice versa*. The action of the twisted tube depends upon the same law which has already been

enunciated, namely, that a surface which is curved in two directions cannot have its curvature increased in one direction without diminishing its curvature in the other direction. In fact, if any portion of the surface of the twisted tube be examined, it will be found to be curved in two directions, but in place of the two curvatures being at right angles to one another, they form an angle more or less acute. The motion of the twisted tube is indicated by a hand fixed to its extremity, or the motion is increased by means of gearing or levers.

A Thermometer made by filling one of these twisted tubes with alcohol or other liquid, and provided with a float, as shown in Figs. 20 and 21, is convenient for enabling brewers and others to ascertain the temperature of large quantities of liquid. The thermometer is allowed to float in the liquid, and the temperature is read off on the dial, without the necessity of lifting the instrument out of the liquid.

All the applications of which these instruments are susceptible need not be mentioned; a few, however, may be alluded to, as illustrating the others.

By applying a tube of suitable dimensions, in connection with a steam boiler, it may be made to open and shut the damper, and thus regulate the pressure in the boiler. A similar arrangement with a Thermometer serves to regulate an Arnott's stove or a furnace.

A steam-engine Indicator is made by removing the cylinder piston and spring of an ordinary Indicator, and substituting a bent or twisted tube. Fig. 22 is a front view, partly in section, and Fig. 23 is a side view of such an Indicator. The bent tube A is placed at the lower part, and connected by a short link to a long lever, which carries the pencil B at its upper end. The paper or card is fixed on a brass plate C, which slides up and down on a fixed guide, and is moved by a pinion working into a rack on the back of the plate. This pinion carries a pulley D upon its axis, which is driven by a string from the beam or parallel motion of the engine. This pulley can be removed, and replaced by others of different diameters; this gives great facility in the application of the Indicator to different engines, especially to direct-acting

engines, where the motion may be taken at once from the cross-head by employing a large pulley. The pulley and pinion are mounted on a spindle passing through a fixed hollow pin. A spiral spring is attached to the fixed pin, and enclosed in a flat circular box, which fits in a cavity in the side of the pulley; this spring serves to keep the string always in a state of tension.

The long lever which carries the pencil turns on a fixed pin at bottom, and prevents the pencil from being moved out of its course by the friction of the paper against it, which might happen if the pencil were attached at once to the tube. The ends of the figure drawn on the paper are slightly curved, and it is necessary to measure the figure with a curved scale of the same radius as the lever.

To show that the principle may be carried out on a still larger scale, M. Bourdon has constructed a single-acting Steam Engine, in which a curved flattened tube made of two steel plates is employed in place of the cylinder and piston. This engine is shown in Fig. 24. One end of the tube A is fixed, and the other is united by a connecting-rod to a crank B, and fly-wheel. A slide valve C, is attached to the fixed end of the tube, and worked by an eccentric D, on the crank shaft. The steam is thus alternately admitted and discharged from the tube, and the engine has thus been worked at a speed of several hundred strokes per minute. To avoid unnecessary loss of steam, the tube is filled with oil, so that the steam only enters a portion of the tube, equal to the increase of its capacity produced by the pressure of the steam. The moving end of the tube A is guided by the lever E, which is adjusted to move in the natural path of the end of the tube without causing any strain. The crank B is slotted with a moveable crank-pin for varying the length of stroke, according to the pressure and the corresponding extent of motion of the tube. When the engine is non-condensing, the crank is set a little past the centre when the engine is at rest, but when the engine is condensing, it is set near half-stroke when at rest, as the tube expands with the steam-pressure, and collapses with the vacuum. The piston friction is avoided in this engine, and it may therefore be found economical for small engines.

In all cases in which accuracy of indications is required in the pressure-gauges, it is advisable to prevent the steam from entering the bent tube, whose elasticity would be reduced as long as it remained in a heated state. This is readily effected by causing the pipe which connects the gauge to the boiler or engine to *descend* to the gauge, as shown at E in Fig. 16 : it will then always remain full of condensed water, and the gauge tube will be kept cool.

Mr. C. Cowper exhibited specimens of the different instruments and models, illustrating the principle of action. He said the steam gauges had come into extensive use in France, and he understood they were found very satisfactory and trustworthy; they were employed by the Government inspectors to test the pressure of steam boilers throughout that country.

Mr. Buckle observed that they appeared most useful gauges for general application, and well suited to many different purposes in practice.

Mr. Peacock said he had made trial of a pair of these steam gauges for the last eight months, on the boilers of a steam boat, working at 25 lbs. pressure, and he had found them quite satisfactory; they had not gone wrong at all during the time, nor had the index taken any permanent set.

Mr. C. Cowper remarked that the application of the principle to a steam engine had not been carried out on a large scale; an engine of about half a horse power had been made to show the application, and had been sent to the Exhibition. The different instruments could be inspected afterwards and obtained at Mr. Dewrance's office in London.

A vote of thanks was passed to Mr. Cowper for his communication, and the meeting then terminated.

[Mr. McConnell having been obliged to leave before the termination of the meeting, the Chair was then taken by Mr. Buckle.]

PROCEEDINGS.

28 July, 1852.

The General Meeting of the Members was held at the house of the Institution, Newhall Street, Birmingham, on Wednesday, 28th July, 1852; Joseph Whitworth, Esq., in the Chair.

The Minutes of the last General Meeting were read and confirmed.

The Chairman announced that the Ballot Lists had been opened by the Committee appointed for the purpose, and the following New Members were duly elected:—

Members.

William Froude, . . .	Totness.
William L. Kinmond, .	Montreal, Canada.
Thomas Ledger, . . .	London.

The discussion, adjourned from the last meeting, was then resumed, upon the paper by Mr. Andrew J. Robertson, of London:—

ON THE MATHEMATICAL PRINCIPLES INVOLVED IN THE CENTRIFUGAL PUMP.

The general result arrived at by the investigation in this paper (see Proceedings Inst. M.E., June 1852, page 90) was that centrifugal action is not an economical mode of applying power for raising water, and that the *theoretical limit* to the *useful effect* to be obtained by centrifugal action alone is 50 per cent. of the *power* employed; a loss of 50 per cent. of the power being caused by the absorption of power in the *tangential* velocity given to the water, whilst the *radial* or centrifugal velocity alone is effective in raising the water.

But the *practical limit* of the *useful effect* is reduced to 75 per cent. of the above 50 per cent., or only $37\frac{1}{2}$ per cent. of the *power* employed, in consequence of the unavoidable losses arising from friction and practical imperfections.

The following supplementary calculations, illustrating the theory advanced in the paper, were supplied by Mr. Stein respecting the results to be obtained from the experiment with Gwynne's centrifugal pump, that was described by Mr. Edwards at the former meeting. In that experiment, recently made by Mr. Edwards with a centrifugal pump containing some further improvements of his own invention, it was stated that 650 gallons of water per minute were raised to a height of $17\frac{1}{2}$ feet, by a revolving disc 13 inches diameter and driven at 800 revolutions per minute: and the driving power was a high pressure steam engine with 8 inch cylinder and 18 inch stroke, working 100 double strokes per minute, with an effective pressure on the piston of about 43 lbs. per inch. The piston being $50\frac{1}{4}$ inches area (8 ins. diameter), and moving at the velocity of 300 feet per minute (200 strokes at $1\frac{1}{2}$ ft.), the *power* expended on the piston of the engine was

$$\frac{50\frac{1}{4} \text{ sq. ins.} \times 43 \text{ lbs.} \times 300 \text{ ft.}}{33{,}000} = 19{\cdot}6 \text{ horse power.}$$

The *useful effect* obtained was

$$\frac{650 \text{ gals.} \times 10 \text{ lbs.} \times 17\frac{1}{2} \text{ ft.}}{33{,}000} = 3{\cdot}4 \text{ horse power.}$$

Therefore the *useful effect* was 18 per cent. of the *power* expended.

According to the theory of the centrifugal pump in the paper, "the *power* expended on the pump is measured by the quantity of water delivered, raised to *twice the height* due to the velocity of the circumference of the arms; whilst the *useful effect* produced is the water delivered, raised to the height of discharge." In the above case the velocity of the circumference of the arms was 2722 feet per minute, and the height due to that velocity (or the height of fall required to obtain that velocity by the action of gravity) is 32·3 feet, and twice the height is 64·6 feet, whilst the height of discharge was 17·5 feet. Consequently the theoretical proportion of the *useful effect* to the *power* expended on the pump would be 17·5 to 64·6; and the

effect obtained in the experiment as above being 3·4 horse power, the *power* required to produce that amount of mechanical effect under these circumstances (without considering the losses from friction and practical defects) would be $3·4 \times \frac{64·6}{17·5} = 12·6$ horse power, or in this case a theoretical efficiency of 27 per cent.

The whole *power* employed having been 19·6 horse power, this leaves 7 horse power, or 35 per cent. of the whole, as the loss due to friction and practical defects, both in the engine and the pump.

The CHAIRMAN asked Mr. Appold to give the particulars of his centrifugal pump, and of the experiments that had been made with it.

Mr. APPOLD exhibited drawings of the pump which he had shown at work in the Exhibition of 1851, and which had been experimented upon by the Jury at the Exhibition. The revolving fan A (see Figs. 1 and 2, Plate 68) is 1 foot diameter and 3 inches wide, having an opening one half the total diameter in the centre of each side for the admission of the water, and a central division plate extending to the circumference, to give a direction to the two streams of water, and convenient for fixing on the shaft; the six arms are curved backwards, terminating nearly tangential to the circumference. The revolving fan is fixed on the end of the driving shaft B, which passes through a stuffing-box in the side of the casing; and it works between two circular cheeks CC, running close without actually touching, whereby the outer revolving surfaces are shielded from the water, but a free ingress is allowed for the water to enter: and a large space DD is left all round the circumference of the fan, to facilitate the escape of the discharged water.

Mr. APPOLD stated that a series of experiments had been tried with his pump at the Exhibition, to ascertain the percentage of useful effect that was yielded by it when raising water to different heights. These experiments were conducted by the Jury of the

Exhibition, and the power employed in each experiment was measured with great accuracy by means of Morin's dynamometer. The driving strap from the steam engine was passed over the first pulley of the dynamometer, and the pump was driven from a second pulley, running loose on the same shaft, and connected to the first by means of a spring, through which all the power was consequently transmitted; and the amount of the driving power was indicated by the extent to which the spring was compressed, which was shown by a continuous pencil-mark upon a paper cylinder connected to the instrument, whereby the actual tension of the driving strap at all periods of the experiment was accurately ascertained. The following results were obtained by this means, and were published in the report of the Jury:—

Experiments on Appold's Centrifugal Pump, with Curved Arms.

Percentage of Effect to Power.	Height of Lift.	Discharge per minute.	Revs. of Pump per minute.	Velocity of Circumference.
	Feet.	Gallons.		Feet per min.
59	8·2	2100	828	2601
65	9·0	1664	620	1948
65	18·8	1164	792	2488
68	19·4	1236	788	2476
46	27·6	681	876	2751
With Straight Inclined Arms.				
43	18·0	736	690	2168
With Straight Radial Arms.				
24	18·0	471	720	2262

In the experiments with straight arms the revolving fan was removed, and others were fixed in its place, exactly similar in other respects, but having straight arms, inclined at 45° as shown in Fig. 5, Plate 69, or radial as in Fig. 6, instead of the curved arms shown in Fig. 4.

Mr. Appold said he had made a series of experiments previously with a similar centrifugal pump, 1 foot diameter, with curved arms; and had constructed a dynamometer to measure the amount

of driving power, by driving the pump from a loose 4 feet drum, and connecting that drum to the driving shaft by a Salter's spring balance, attached to an arm which was fixed on the shaft and thus pulled round the drum. The extent to which the spring was stretched showed the amount of force employed in the driving power, and this was marked by a slide upon the balance, which was pulled out with the spring, and remained in the extreme position it had been pulled to, so that the extreme pressure could be read off when the machine was stopped. The following results were thus obtained :—

Experiments on Appold's Pump with Curved Arms.

Height of Lift of the water, 5½ feet in each case.

Percentage of Effect to Power.	Discharge per minute.	Revs. of Pump per minute.	Velocity of Circumference.	Driving Power at Circumf. of Pump.
	Gallons.		Feet per min.	Lbs.
0	1	359	1128	8
21	100	375	1177	11
55	400	394	1238	16
66	700	427	1341	21½
70	1000	474	1487	26½
72	1300	518	1627	30¾
70	1600	580	1822	34½
63	1800	607	1907	37½

Mr. Clift remarked that it appeared from the experiments there was a certain velocity which gave the maximum duty in centrifugal pumps, and they were more limited in application on that account than piston pumps.

Mr. Appold replied that the same circumstance applied to a common pump, though not to the same extent; if an ordinary pump, for instance, capable of delivering 1400 gallons per minute with the best duty, were set to work so as to deliver only 400 gallons per minute, the duty or percentage of useful effect would certainly be much reduced: as every pump must be proportioned to the work to be done, or it would not give a maximum effect. In the centrifugal pump, the velocity of the circumference must be constant for all sizes of pump for the same height of lift; that is, a

pump 1 inch diameter must make 12 times the number of revolutions per minute of one 12 inches diameter, and both pumps would then raise the water to the same height; but the quantity of water delivered would be 144 times greater in the 12-inch pump, being in proportion to the area of the discharging orifices at the circumference, or the square of the diameter, when the proportion of breadth was kept the same, namely 1-4th of the diameter in each case.

Mr. Appold showed a small pump, of the same proportions but only 1 inch diameter (the same actual size as the engraving in Plate 68), with which similar experiments had been tried as with the 1-foot pump, and proportionate results were obtained.

This pump	1 inch diam.	discharged	10	gals. per min.
And a pump	1 foot	,, ,,	1440	,, ,, ,,
Consequently,	10 feet	,, ..	144000	,, ,, ,,

the height that the water was lifted being the same in each case, if the velocity of the circumference was the same.

A velocity of 500 feet per minute of the circumference raised the water 1 foot high, and maintained it at that level without discharging any: and a double velocity raised the water to four times the height, as the centrifugal force was proportionate to the square of the velocity; consequently

500	feet per min. raised the water	1	foot without discharge.
1000	,, ,, ,,	4	,, ,,
2000	,, ,, ,,	16	,, ,,
4000	,, ,, ,,	64	,, ,,

The greatest height to which the water had been raised without discharge, in the experiments with the 1-foot pump, was 67·7 feet, with a velocity of 4153 feet per minute, being rather less than the calculated height, owing probably to leakage with the greater pressure.

A velocity of 1128 feet per minute raised the water $5\frac{1}{2}$ feet without any discharge; and the maximum effect from the power employed in raising to the same height, $5\frac{1}{2}$ feet, was obtained at the velocity of 1678 feet per minute, giving a discharge of 1400 gallons per minute from the 1 foot pump. The additional velocity required to effect the discharge was 550 feet per minute; or the velocity required to effect a discharge of 1400 gallons per minute through a

1 foot pump, working at a dead level without any height of lift, was 550 feet per minute. Consequently, adding this number in each case to the velocity given above at which no discharge took place, the following velocities were obtained for the maximum effect to be produced in each case:—

1030 feet per minute velocity, for	1 foot height of lift.	
[illegible]	4	„
[illegible]	16	„
[illegible]	64	„

Or in general terms the *velocity in feet per minute* for the circumference of the pump to be driven at, in order to raise the water to a certain height, was equal to

$$[illegible] + ([illegible] \sqrt{\text{height of lift in feet}}).$$

Mr. Benjamin Gibbons observed that in the percentage of effect obtained from a given power he did not think the centrifugal pump could exceed an ordinary piston pump of good construction, where a large quantity of water was to be lifted a small height.

Mr. Appold replied that he did not know a piston pump that yielded so good a duty as 70 per cent., which might be taken as the effect obtained from his centrifugal pump when working at the most effective velocity. The greatest result obtained in the experiments at the Exhibition was 68 per cent., but some allowance had to be added in that case for the leakage through several large wood valves, 4 feet long, faced with leather, which were fixed in the suction-pipe of the pump, to pump the water from different levels.

Mr. B. Gibbons said he considered that a good plunger pump would exceed 70 per cent. in duty.

Mr. Appold remarked that there were some situations where it was the most important consideration for a pump to be quickly and readily applied, that would discharge a very large quantity of water; and the centrifugal pump was found very advantageous in such cases, where the work could not probably be effected by other means. In one instance, in putting in the foundations of harbour works at Dover, a large quantity of water of 2000 to 3000 gallons per minute was pumped out by one of these pumps, which could not have been accomplished in the time by any other means, from the difficulty and delay of fixing ordinary pumps of that great capacity. The

centrifugal pump possessed another important advantage for such applications, from having no valves in action when at work, which enabled it to pass large stones, and almost anything that was not too large to enter between the arms.

The largest pump constructed at present on this plan was erected at Whittlesea Mere for the purpose of draining, and had worked there nearly a year with complete success. The pump was $4\frac{1}{2}$ feet diameter, with an average velocity of 90 revolutions or 1270 feet per minute, and was driven by a double-cylinder steam engine, with steam 40 lbs. per inch and vacuum $13\frac{1}{2}$ lbs. per inch; it raised about 15,000 gallons of water per minute through an average height of 4 or 5 feet. The cost of the engine and pump was about £1600. The following experiments were tried to ascertain the percentage of effect obtained from the pump; the power employed being measured by taking indicator figures from the engine, deducting in each case

Experiments on Appold's Pump at Whittlesea Mere.

No. of Experiment		1		2		3		4	
		Feet.		Feet.		Feet.		Feet.	
Velocity of Circumference of Pump, in feet per minute		1159		1357		1301		1329	
		Ft.	Ins.	Ft.	Ins.	Ft.	Ins.	Ft.	Ins.
Height of lift of the water, in feet and inches		3	0	4	1	5	0	5	11
Depth of water at point of overflow	A	1	1	1	$5\frac{1}{2}$	1	$3\frac{3}{8}$	1	2
Ditto at 17 feet distance	B	1	7	1	$8\frac{1}{2}$	1	$6\frac{3}{8}$	1	5
		Gals.		Gals.		Gals.		Gals.	
Gallons discharged per minute, according to the depth	A	12429		14223		11706		9545	
Ditto ditto...	B	16104		18023		15288		13606	
Theoretical discharge...		17400		21587		15768		12803	
		HP.		HP.		HP.		HP.	
Horse power effective in raising the quantity	A	11·34		16·88		17·79		17·17	
Ditto ditto...	B	14·70		22·38		23·24		24·49	
Horse power employed to work pump		23·00		40·90		29·90		39·80	
		Per cent.		Per cent.		Per cent.		Per cent.	
Percentage of effect to power employed, by calculation ...	A	49		41		60		43	
Ditto ditto...	B	64		55		78		61	

the power that was indicated when the engine was working at the same speed without the pump, which was found to take 10·6 horse power. The quantity of water discharged was measured by calculating the overflow from an opening 6 feet wide in each case. The true result would be between the two calculations A and B, and the maximum effect might probably be taken at about 68 per cent. of the power; the same result as that obtained from the Exhibition experiments.

Mr. B. GIBBONS observed that this centrifugal pump appeared a very ingenious machine, and very useful for some purposes; but the object was to obtain the plan which gave the greatest percentage of duty or the least waste of power. He was of opinion that for ordinary lifts, of say 10 to 30 feet, a bucket pump of good construction performed more than 70 per cent. duty, and would consequently be found more economical in power than a centrifugal pump.

Mr. APPOLD said he found the centrifugal pump more advantageous for low lifts below 20 feet than for higher lifts; but its most advantageous application was as a tidal pump, where the height of lift was continually varying, because it discharged more water the lower the lift, the pump still going at the same speed; but other pumps generally discharged only their cubic contents, no matter how low the lift. In one centrifugal pump, erecting at Shoreham, the height of lift would vary between 30 feet and nothing at different times of the tide.

Mr. ELWELL enquired whether a centrifugal pump would be advantageous to be applied with a water-wheel, to assist in keeping the water-wheel at work, by returning a portion of the water when the supply was short.

Mr. APPOLD replied that one of these pumps had been applied for that purpose by Messrs. Curtis, at the Hounslow Powder Mills, to keep the water-wheel going constantly in the summer time when short of water. The water was pumped up 7 feet high, by running the steam engine a few hours extra at night, at a small expense, which completely kept up the supply for the water-wheel, and avoided bringing the engine any nearer the powder mills. The

centrifugal pump was very convenient and economical for this purpose, and the result was found so satisfactory that a second pump was going to be erected for a similar purpose.

The CHAIRMAN enquired whether Mr. Appold considered the spiral form of the arms an essential point in his pump, instead of the radial arms in the other centrifugal pumps.

Mr. APPOLD replied that the oblique position of the arms was most important, and the large amount of duty obtained from his pump was entirely owing to this ; he had at first tried straight arms inclined at 45°, but he found that the curved arms ending nearly in a line with a tangent to the outer circumference gave the greatest effect. The superior action of oblique arms to radial arms might be illustrated by supposing a vertical arm AB (see Fig. 3, Plate 68) to move in a straight line to CD, instead of moving round in a circle in the pump; and the body A, representing a particle of water, would then be simply moved along to C with the arm, without having any tendency to be propelled outwards along the arm to B. But if an oblique arm AE were employed, moving in the same direction as before to the position CB, it propelled the particle A outwards towards B, having an inclined-plane action to push the particles of water outwards from the centre towards the circumference. When this was applied to a circular motion, and the direction AC bent into a circle, the inclined arm AE became curved in a spiral direction like the arms in the pump. The comparative value of the different forms of arms was proved by the experiments at the Exhibition mentioned before; the curved arms gave a duty of 68 per cent., the inclined arms 43 per cent., and the radial arms only 24 per cent.; and he understood that the two other centrifugal pumps of Mr. Gwynne and Mr. Bessemer, which were also experimented upon at the Exhibition, did not give a higher duty than 24 per cent., as they both had straight radial arms. The experiments would all be published in the report of the Jury. The facts quite bore out therefore the conclusions arrived at by the investigation in the paper that had been read, as to the effects to be obtained from centrifugal action with radial arms.

Mr. CLIFT observed that, if there were no advantage in amount of duty in Mr. Appold's pump, there was certainly a great advantage in point of cost, and in convenience of application for many purposes. He proposed a vote of thanks to Mr. Appold for his attendance at the meeting, and the information he had afforded.

The vote of thanks was then passed.

The following paper, by Mr. George H. Bovill, of London, was then read:—

ON A NEW IMPROVED SCREW PROPELLER.

The Screw Propeller has now become so important a feature in steam navigation, that the writer has thought it a subject of sufficient interest to induce him to bring under the consideration of the Institution of Mechanical Engineers, as well as the owners of screw vessels, some most important experiments made under his own directions upon a new propeller, invented by Mr. Griffiths, which is in its form and general principles diametrically opposite to the screws adopted by the Government, and by all the marine engineers of the present day.

The screws generally used, as shown in Plate 70, are formed of two blades continued down to the shaft, the boss or centre being reduced to the smallest possible size consistent with strength. The Government, by their elaborate experiments with the "Rattler," "Minx," &c., appear to have determined thus far the general outline of principles for constructing the screw; but the correct pitch, diameter, and length, as well as the number of blades necessary for obtaining the best results, are still matters upon which scarcely two engineers agree. The equally important point, the correct speed

to drive the screws, is a still greater matter of doubt; and notwithstanding the great labour and expense that have been bestowed on the subject by many engineers of eminence, to whom we are indebted for bringing the subject to its present state of practical utility, yet there appear no fixed and certain rules arrived at for constructing the screws and determining the speed at which they shall be driven to produce a given result. On reference to Mr. Murray's valuable work on steam vessels and the screw, it will be found, on comparing the various vessels in her Majesty's navy, that the most singular circumstances occur in the comparative proportions of screws, as well as the speeds expected from the engines compared with the actual revolutions obtained on trial.

In the year 1849 Mr. Griffiths explained to the writer his then crude notions for removing the defects of the ordinary screw. The idea was so original, and appeared to him so correct, that he at once instituted a series of experiments, which proved to him the great importance of the invention, and induced him to make further experiments: these he believes will have removed the uncertainty and objections that surround the ordinary screw, thus rendering its future application and results as certain as the paddle-wheel.

The construction of the New Propeller is shown in Plate 71. Fig. 5 is an end view in a line with the shaft; Fig. 6 is a longitudinal section, and Fig. 7 a plan. Each of the propeller blades A A A is separate, and ends in a strong spindle B, which turns in a socket in the centre boss fixed on the propeller shaft C. A cross arm D is fixed in the spindle B, to turn round the blade and hold it in any required position, this arm working in a slot in the socket; and the end of the arm is connected by a pin to the block E, which slides in an oblique groove (shown in the plan, Fig. 7). This groove is formed in a ring F, which slides upon a feather, so as to revolve with the main shaft, and is moved by the bell-crank lever G, which is centred in the rudder post of the vessel, and is worked by a screw and handle upon deck, on the top of the rod H. By this means the pitch of the propeller blades is easily altered to any required degree, and maintained in the same

position, the strain being very small, as the blades are nearly balanced like a throttle-valve, having only a slight surplus of tendency to increase the pitch, or become more in line with the shaft. The whole of the apparatus is contained within the spherical casing H, one third the diameter of the propeller, and is thereby effectually protected from injury.

It will be seen that the form of this propeller is opposed to all the received notions of a correct screw propeller. The first leading feature is that, instead of continuing the blades down to the shaft and keeping the centre boss as small as possible, one third of the entire diameter is filled up as a sphere, as shown by the dotted circle in Figs. 1 and 2, Plate 70. In the experiments made by Mr. Griffiths and the writer, it was ascertained that the centre part of the blades of the ordinary screws, included within the dotted circle, absorbed 20 per cent. of the power, without having any propelling effect, in consequence of that part of the blades (particularly in coarse-pitched screws) being nearly in a line with the shaft; the effect when working being to hurl the water off by its flapping and centrifugal action at right angles to the shaft, and seriously to disturb the more solid water upon which the more effective portion of the screw should act. The great vibration at the stern of all screw vessels arises from this flapping action of the flatter portion of the blades in their downward course, striking the denser water below them, which, affording a greater resistance than the water above the blade in its upward course, produces this evil vibration at an enormous sacrifice of power. The effect of this destructive action can be appreciated by the fact that screw vessels, if trimmed say 2 inches by the stern when under canvas or at anchor, will suddenly be 2 inches down by the head the moment the engines are set to work: in point of fact, a large amount of engine power is exerted in lifting the stern of the ship out of the water, by the action of the flat part of the screw blades, as described.

The ball shown in the drawing is made to cover this destructive portion of the screw blades, or rather is substituted for the central third portion of the screw, as shown by the dotted circle in Figs. 1

and 2, Plate 70. It will be seen that the power required to revolve this ball in the water at a great velocity is insignificant compared with driving two or three comparatively flat blades of the same diameter, which may be fairly compared to the centre of a centrifugal pump. That there can be no tendency to vibrate the stern of the vessel is obvious, nor does the trim of the vessel alter in the least degree when under the action of the new propeller. Moreover from the water not being violently agitated by the centrifugal action, the effective parts of the propeller blades are screwing in stiller and more solid water, producing a better result and with a considerably less amount of slip. The water leaves the propeller in a direct line with the vessel, and without the commotion resulting from the ordinary screw. The strength of the screw is much increased by this form, which also affords great facility for replacing the blades in case of accident, to which screw vessels in channel and river navigation are peculiarly liable.

The second important feature is the *form of the blades*, which instead of being larger at the extremities are precisely the reverse. The best form the writer has found to be as shown in the drawing, Fig. 5, Plate 71. The breadth of the blades is the full diameter of the sphere at the root, tapering to two-thirds of this size at the periphery, at which part they are only about one third of the size of the ordinary screw blade; and with these proportions, so complete is the hold this propeller has upon the water, that it has been requisite in practice even to reduce the diameter considerably below that of the ordinary screw.

The water which follows the wake of the ship, and what the sailors call the "dead water," may be compared to the eddies below the piers of a bridge through which a rapid tide runs, where the water is "dead" or in a state of rest, the more so at the very centre of the pier. In a precisely similar condition is the dead water of a vessel, the water being most solid towards the centre, and gradually becoming less so until mixed in the current running beyond the width of the ship. It must be obvious that the nearer the work can be applied to the screw shaft, the better mechanical result will

be obtained: the arrangement of the blades of the new propeller has accordingly been so contrived that their broad part is made at the ball, so that advantage is taken of the central dead water just described, to obtain the utmost duty from the propeller blade at its root or as near the screw shaft as the central ball will admit. The blades are reduced towards the periphery to meet the difference of velocity at which they travel through the water. So effective is the hold of these blades upon the water from the causes described, that the writer has found in practice the speed of the propellers can be reduced, with the greatest advantage, one third below the velocity found necessary for the ordinary screw: a fact which every engineer will admit to be of great value, seeing the many mechanical difficulties which present themselves in obtaining the speed hitherto considered necessary.

The screw has hitherto been applied almost entirely as auxiliary power, and where large power has been employed it has never yet been made to equal the speed of the paddle-wheel. The imperfections of the screw appear hitherto to have placed a limit on the speed which it was possible to obtain.

In those vessels where a large amount of engine power was applied, no adequate increase of speed was obtained; and in the case of the "Rifleman" and others, which were altered and had the engine power absolutely reduced one half, as good a result was obtained after the alteration as with the larger power: showing that beyond a given power the water is screwed through the screw, instead of the vessel being screwed through the water. This action takes place in all screw vessels to a most serious degree, in going head to wind or in towing, when the engines make their full number of revolutions but have little effect in propelling the ship. The perfect hold that the new propeller has also under such circumstances upon the water bids fair entirely to remove these difficulties, and will tend greatly to increase the value of the screw as a propeller.

The new propeller was applied to a tug-boat, the "Lady Emily," 12 horse power, 3 ft. 8 ins. diameter of screw, on the Kennet

and Avon Canal, under the direction of Captain Morrice, R.N., the manager: and the results showed that with one barge laden with 60 tons, she went from Bath to Bristol, deducting stoppages in going through locks, in $2\frac{3}{4}$ hours, the distance being 18 miles. As other barges were added, the speed was reduced, and the engines were pulled up in exact proportion to the reduction of speed. The revolutions of the propeller without any barge in tow were 210 per minute; with a 60 tons loaded barge they were reduced to 180; and with two barges to 160 revolutions per minute.

The question of the *pitch of the screw* appears hitherto to have baffled all those who have experimented upon it; the ordinary theory being that an increase of the pitch should either pull up the engines, or increase the speed of the vessel in proportion to the increase of pitch. But all the practice hitherto has proved this not to be the case; and consequently the screws have been made without any power of altering the pitch to meet the variations of winds and currents, to which all sea-going vessels are subject; and they have thus been deprived of what would appear to be the most valuable feature of the screw, namely its power of adapting its pitch to meet every contingency. It has been found by the experiments that with the new propeller the engineer can control the speed of the engines at pleasure, by increasing or diminishing the pitch of the blades; so that in a fair wind the full power of the engines may be exerted in effectually propelling the vessel, instead of consuming fuel in driving round the engines (with a fine-pitched screw) to no purpose; and again, in going head to wind, by diminishing the pitch the engines can be made to give out their utmost duty, with a certainty of effectually propelling the vessel. The large central ball affords the opportunity of constructing a most simple and effective arrangement for altering the pitch of the blades, and feathering them parallel to the shaft when not required for propelling. The captain or engineer of the vessel can alter the pitch at pleasure without even stopping the engines, the speed of which is as completely under control by means of this apparatus as with a throttle-valve.

A most serious disadvantage hitherto of the screw as a propeller, compared to the paddle wheel, has been the great difficulty of going astern; and many serious accidents have happened to screw vessels in crowded navigations, from its being out of the power of the captain to go quickly astern when in difficulty; so soon as stern way is obtained, screw vessels will not steer and become unmanageable. During the experiments in the "Ranger" with the new propeller, the vessel was frequently stopped when at full speed, the engines reversed, and the ship brought quickly astern, nearly as quick as a paddle vessel; and a run was made above a mile astern at full speed, between Woolwich and Erith, steering among the various craft as easily as when going ahead. This fact affords further convincing proof of the complete power which this propeller gives the captain over the vessel. To vessels of war this power of going astern, which they do not now possess, will be of enormous value in manœuvring in an engagement.

It will be clear by the accompanying Table of trials made upon the "Eagle," that as the pitch was increased, so was the engine brought up in her speed. The comparative slip between the new screw and the old one at same pitch, 7 ft. 6 ins., is 272 yards per mile or 13 per cent. with the former, against 665 yards or 27 per cent. with the latter; the gain with the same pitch being an increased speed of $\frac{3}{4}$ mile per hour, with 27 revolutions per minute less of the engine, making 16 per cent. less consumption of power and coals. At the 9 ft. 6 ins. pitch the increased speed is $\frac{5}{8}$ mile per hour, with 35 revolutions per minute less of the engine, making a saving of 22 per cent. The Table also contains trials of the "Ranger," 300 tons, at London, and the "Weaver" at Liverpool: the whole of the experiments illustrating the foregoing arguments. A sheer plan of the "Weaver" is given in Fig. 4, Plate 70.

Table of Comparative Trials of Griffiths' Screw Propeller.

Trials of the	Description of Screw.	No. of Trial.	Screw Propeller. Diameter.	Screw Propeller. Pitch.	Screw Propeller. Extreme Angle.	Screw Propeller. Revolutions per min.	Engine. Revolutions per min.	Engine. Steam Pressure per inch.	Engine. Vacuum pressure per inch.	Time of Running the measured nautical mile.	Speed Statute miles per hour. Boat.	Speed Statute miles per hour. Screw.	Slip of Screw.	Gain or saving in Power.	Gain or saving in Speed.
			Ft. Ins.	Ft. Ins.	Degrees.	No.	No.	Lbs.	Lbs.	Min. Sec	Miles.	Miles.	Percent	Percent	Percent
"Eagle" at Bristol.	Old	1	4 10	7 6	26½	200	200	38	—	5 31	12·36	17·00	27½	—	—
	New	2	4 10	6 6	23½	195	195	35	—	4 59	13·80	14·40	4	12¾	11¾
	..	3	4 10	7 6	26½	173	173	37	—	5 23	12·79	14·74	13¼	16¼	3½
	..	4	4 10	8 6	29½	171	171	34	—	5 25	12·70	16·51	23	16¾	2¾
	,,	5	4 10	9 6	32¼	165	165	35	—	5 15	13·12	17·89	26¼	22¼	6
"Ranger" at Long Reach.	Old	6	7 0	6 10	17¾	159	60	12	13½	7 3	9·76	12·33	20¾	—	—
	New	7	5 10	10 0	28½	116	14	10	12¼	6 36	10·45	13·23	21	36	6¾
	..	8	6 2	6 8	19	143	51	12	12	5 8	13·45	—	—	—	—
	,,	9	6 2	6 8	19	132	50	—	—	11 14	6·14	—	—	—	—
	,,	10	6 2	6 8	19	137	52	12	12	8 11	9·80	10·42	6	—	—
"Weaver" at Liverpool.	Old	11	3 3	4 6	24	332	83	11	14	6 2	11·40	16·97	32	—	—
	New	12	3 3	4 6	24	260	65	11	14	5 37	12·38	13·29	8	27	7½

EXPLANATION OF TABLE.

Trials of the "Eagle" at Bristol, June, 1851.

Single high pressure Engine, cylinder 28 inches diameter, [illegible] inches stroke, screw worked by direct action. Vessel and Engine by [illegible] and Co., Bristol.

No. 1 Trial—Average of several pair of runs with Ordinary Propeller.

Nos. 2 to 5—Average of four pair of runs with New Propeller.

NOTE.—The New Propeller was made 4 feet 2 inches in diameter, but the opening in the vessel having been increased during construction to 5 feet, the propeller was enlarged in diameter by welding pieces on the points of the blades, which were thereby thrown out of their proportionate size.

Trials of the "Ranger" at Long Reach, December, 1851.

Pair of Condensing Engines, cylinders 27 inches diameter, 21 inches stroke, screw worked by gear of [illegible] to 40. Vessel and Engines by Miller and Ravenhill.

No. 6 Trial—Single run with Ordinary Propeller, with a 40 minutes ebb-tide and wind in favour.

No. 7—Single run at top of tide, with New Propeller at the coarsest pitch.

NOTE.—The "Ranger" being employed on a station from which it was impossible to spare her for the purposes of experiment, there was no opportunity of making a proper set of trials to compare her ordinary screw with the new propeller; but her speed was taken at the measured mile, when going out with a cargo, with a 40 minutes ebb-tide and wind in her favour, as given in No. 6 trial.

No. 8—Run down with tide, with the New Propeller.

No. 9—Run up against tide, with the New Propeller, showing a reduction of 4 revolutions per minute of the engine with same pitch of screw.

No. 10—Average of Nos. 8 and 9 trials.

NOTE.—The pitch of the New Propeller was subsequently reduced to 5 feet 2 inches when running against tide, which allowed the engines to get up to 70 revolutions per minute, whereby a speed of 7·95 statute miles per hour against tide was obtained; and this added to the run down with tide (No. 8) at 6 feet 8 inches pitch gives an average speed of [illegible] miles per hour.

Trials of the "Weaver" at Liverpool, June, 1852.

Pair of Condensing Engines, cylinders 22 inches diameter, 15 inches stroke, screw worked by gear of 4 to 1. Vessel by John Laird, Birkenhead; Engines by Fawcett Preston and Co.

No. 11 Trial—Average of pair of runs with Ordinary Propeller, from Woodside pier to Eastham pier, $5\frac{3}{4}$ statute miles.

No. 12—Average of pair of runs with New Propeller, between the same places: with same state of tide as No. 11 trial in the preceding week, but wind strong and unfavourable and a heavy sea.

A model illustrating the principle of the new propeller was exhibited by the Secretary (Mr. Bovill having been prevented from attending the meeting). The model showed an ordinary screw propeller, which was divided into three portions, like the drawing in Plate 70, so that one-third of the propeller in the centre could be removed, and a ball of the same diameter substituted, upon which the two blades forming the remainder of the propeller were then fixed, in the same relative position as in the original propeller.

Mr. Preston said he had witnessed the experiments made on the "Weaver," that were described in the paper, and could confirm the statement made as to the superiority of the new propeller in the diminution of slip and the increase of speed of the vessel. He did not perceive any superiority in the amount of back-water produced; in going ahead the vessel dipped astern with both propellers, and he did not perceive any difference; but it was a very flat vessel, and the bows rose so abruptly that the head was forced up by the action of the water. The experiments were tried in the Mersey, above Liverpool, and the effect of tide was deducted by trying the experiment both ways. He doubted the practicability of the apparatus for altering the pitch being kept in working order at sea for any length of time.

Mr. Ramsbottom remarked that, if the pitch of the blades in an ordinary screw propeller were the same throughout down to the centre boss, every part of the blade would have the same advancing motion in the water, and would screw correctly through it; and he could not understand how the centre portion of the blades could have the injurious flapping and centrifugal action mentioned in the paper, when the screw was advancing through the water, as such an action could only take place if the arms were to revolve whilst the vessel was stationary.

Mr. Appold observed that the ball would deflect the water, and throw a body of water on to the blades, giving them more water to act upon, and preventing the water from slipping away from the pressure of the blades, through the centre of the propeller, as in the ordinary form with an open centre. Supposing the propeller were working through a tube of the same diameter as the circumference

of the arms, the centre ball would occupy one third of the diameter of the tube, and reduce its effective diameter, causing all the water to pass through the reduced area, and so bringing more water in contact with the arms in the same distance, and affording them a more solid abutment for their action.

Mr. B. GIBBONS thought it was to be inferred from that argument that it would be advantageous to enlarge the shaft to the size of the ball, so as to fill up the displacement of the ball; and that would avoid the resistance offered by the front of the ball being dragged through the water.

Mr APPOLD suggested that a conical form might be preferable for the front of the ball, to deflect the water from the centre on to the arms. He had found that best in his centrifugal pump, in which there was a similar action, and the water entering at the centre had to be suddenly deflected at right angles into a radial direction: he had tried a pump having the centre bell-mouthed from the inside, with the object of affording a more free entrance for the water: but he found it gave less results than the form he had adopted, having a square edge inside the opening, and the centre coned from the spindle to the centre disc.

The CHAIRMAN observed that further experiments with the new propeller were very desirable; and he proposed a vote of thanks to Mr. Bovill for his paper, which was passed, with a request that he would furnish to the Institution the results of further trials of the propeller.

The following paper, by Mr. W. Keld Whytehead, of London, was then read:—

ON A NEW DIRECT-ACTING STEAM PUMP.

This Steam Pump is of American invention, and has been used extensively there for feeding the boilers of marine engines. It is however well adapted for any purpose, where a moderate quantity of water has to be raised, and where a rotary motion is not required. The drawing Plate 72 shows one that is fixed at the Great Northern Railway Station at King's Cross, London, and used for supplying the station with water.

Its chief peculiarity is that the stroke of the piston and of the pump plunger is regulated without the use of a crank, so that the motion of the plunger is nearly uniform for the whole length of the stroke. Mr. Ericsson (of Messrs. Braithwaite's firm) made a fire-engine on this principle some years back, and Mr. Penn formerly used the same arrangement for donkey engines for steam boats; but both of these kinds of engine were deficient in smoothness of working, a difficulty which has been overcome by Messrs. Worthington and Baker in the present pump by very simple and effectual means.

Fig. 1, Plate 72, is a longitudinal section, and Fig. 2 a transverse section of the pump. A is the steam piston, and B the pump plunger, both bolted to the same piston rod. The plunger is double-acting, and works through metallic packing CC. DD are the suction valves, and EE the delivery valves, consisting each of a ring of india-rubber, rising on a brass spindle with a guard at the top, and falling upon a circular plate perforated with holes, as shown enlarged in Fig. 3. In the plunger are bored a few holes HH. which have the effect of opening a communication between the two ends of the pump barrel at each end of the stroke, thus giving the water as it were a partial elasticity, allowing it to continue its forward motion by flowing through the plunger during the moment that the plunger becomes stationary. This enables the plunger to commence its return stroke without any shock or concussion.

The slide valve I is moved by the tappet K, fixed on the piston rod, and striking either of the nuts L or M. Steam is admitted *under* the slide, as shown, since the motion of the slide in one direction has to admit steam for the piston moving in the opposite direction. A steam buffer is provided for the slide, to remove the concussion; N is a piston attached to the slide rod, working in a cylinder, which has a small groove cut in the bottom of it. This cylinder is filled with steam from the slide chest through a small hole in the end, and the steam is compressed by the piston N at each stroke of the tappet K, thus forming a buffer or spring of very perfect elasticity; and the compressed steam escapes immediately afterwards to the other side of the piston N, through the groove in the bottom side of the cylinder, thus preventing any recoil of the valve. O is an air-vessel on the delivery pipe, and the suction pipe P, Fig. 2, is carried up above the pump to form a head, in order to make the flow of water more uniform. In starting the pump, the hand-lever R is put into gear with the nut L, as shown by the dotted lines, and the valve is moved by hand for a few strokes, to let on the steam, until the engine is fairly started.

This pump has been at work for five months at King's Cross Station very satisfactorily, the only repairs necessary having been about one day's work. It has to draw the water 14 feet perpendicular, and forces it 30 feet perpendicular. The usual speed is 40 to 50 double strokes per minute, but there is no difficulty in working it double that speed if desired. The uniformity of the stream of water delivered is very remarkable, and seems to indicate that there is no loss of power, or to speak more correctly that there is never an excess of power to impart an undue velocity to the water. The small space occupied by the pump is an advantage of some importance when used for marine purposes.

Mr. Ramsbottom observed that he had seen the pump at work at the King's Cross Station, and it certainly worked well, with very little vibration, and delivered a steady uniform stream of water;

but it was a defect that the economy of working expansively could not be obtained with a pump on that principle, as the full pressure of steam was required to complete the stroke. There was a simplo contrivance in the shut-off valve of the delivery pipe, for changing the direction of the discharge; the valve was constructed with a double face, and fitted to shut the opening on either side, so as to pump either into the tank or into the fire-hose, by screwing the valve spindle in one direction or the other.

The Secretary said that Mr. Whytehead had expected to give the results of a trial of the pump to ascertain the duty yielded by it, by measuring the quantity of water discharged and taking indicator figures from the engine; but he had not yet been able to make the experiments.

Mr. Preston remarked that a direct-acting steam pump had been constructed by Mr. Penn for feeding marine boilers, but that he adopted a crank motion now for the purpose, finding the vibration and shock of the tappet motion too great for working the valve.

Mr. Ramsbottom observed that the steam buffer-spring upon the valve spindle in this pump appeared to be very effectual in taking off the shock, even when working at a considerable speed; and the equilibrium established between the two ends of the pump, by means of the holes through the plunger, caused the valves to close down upon their seats almost before the return stroke, and prepare the pump for the reversed action of the steam.

Mr. Middleton thought there would not be any advantage gained with this pump in simplicity over a crank engine, and it would not be so economical in power, from not being able to work the steam expansively.

Mr. Appold enquired how long the india-rubber valves were found to last in pumps.

Mr. Preston said the india-rubber valves answered very well in the air-pumps of marine engines; they were always used for screw vessels, on account of the rapid action of the valves with short-stroke engines, for which metal valves were not applicable. The time they lasted varied very much with the circumstances; vulcanised sheet india-rubber only should be used, and might last some months,

perhaps a year; but the canvas valves coated with india-rubber soon decayed.

Mr. Clift remarked that a new mode had been brought out of preparing india-rubber with sulphuret of lead, instead of vulcanising it with sulphur, which was said to render it better and more durable: but he did not know the results of trial.

Mr. Apsold doubted whether vulcanised india-rubber would stand a constant elastic action for a year, or even a shorter period. He had tried some india-rubber springs for window-shutters, and found they failed in three or four months: it was some years back, and he did not know whether the process of manufacture had been improved since.

Mr. B. Gibbons said he had found the elastic bands for papers, after lying by for two or three years, lost their elasticity and became decayed.

Mr. Adams enquired whether the vulcanised india-rubber rings in railway carriage buffers and draw-springs were found to decay.

Mr. H. Wright said he had found the rings in buffers still remaining good after three or four years' work: the india-rubber was subjected to compression only, and was protected from wet. He had several hundred wagons under his charge working with india-rubber buffers and draw-springs, which were all doing very well. The only failure of the india-rubber rings that had been experienced amongst them was in consequence of the intermediate plates or washers between the rings, which were made at first of cast iron and too thin, becoming broken and then cutting the india-rubber; but that had been remedied by using stronger wrought-iron washers.

Mr. S. Lloyd observed that the india-rubber buffers had also been several years in extensive use on the Great Western Railway for all the carriages, and he believed with satisfactory results.

Mr. Clift remarked that it had been explained by the maker, Mr. De Bergue, at a former meeting of the Institution, that there was some imperfection in the vulcanised india-rubber first manufactured, which made it less durable, but the defect was removed in all the subsequent manufacture.

Mr. Preston observed that the india-rubber in pump valves was subjected to more severe wear, from the constant rapid bending and the action of the water, than the mere compression in buffer springs. Some of the valves proved defective at first in consequence of being cut transversely from a cylinder of india-rubber, which was manufactured by rolling up a long sheet; these valves split open in the roll and became defective, from the constant action upon them; but all he now used were cut out of a single flat sheet, and were found to stand very well.

The Chairman proposed a vote of thanks to Mr. Whytehead for his description of the pump, which was passed; and expressed a hope that he would furnish at another meeting the results of a trial of the duty yielded by the pump.

The following paper, by Mr. John E. Clift, of Birmingham, was then read :—

ON IMPROVED FIRE-BRICK GAS RETORTS.

The object of this paper is to describe a plan for constructing Gas Retorts, which the writer has had in use several years at the works under his management, and has also adopted at various other towns ; and the only apology he has to offer for bringing it before the meeting is the request of the Council of the Institution to furnish the practical results of the working of the plan.

The first great desideratum in a gas-generating retort is on all hands acknowledged to be *surface* : a large surface, upon which may be spread a thin layer of coal. This was early shown by Mr. Clegg,

in his invention of the revolving-web retort, in which the only difficulty in working was the destructible nature of the material that it was composed of.

The second condition required is that this large surface shall be *economically heated*. A strong opinion existed for a long time against the use of fire-clay for retorts, in consequence of the inferior heat-conducting properties of that material compared with iron; but experience has proved that, with a given weight of fuel, as large a quantity of gas can be generated with fire-brick retorts as with iron. This may be partly accounted for by the fire-clay losing less of its heat on being exposed to the air whilst charging, and on the cold charge of coal being first thrown in; or, in other words, the greater mass of fire-clay acts as a reservoir of heat, and does not become so readily exhausted when a large demand is made upon it, but on the contrary maintains a greater uniformity of temperature throughout the process. This is easily demonstrated by observing the small quantity of gas made from an iron retort compared with a fire-brick one during the first hour after charging. It is also partly accounted for by the iron retorts, as they are generally set, being so covered and shielded with fire-bricks to preserve them from destruction, as to partake as much of the character of clay retorts as of iron.

The following table, which is the average of a number of experiments, gives the quantities of gas generated, as indicated by the meter, from iron and fire-brick retorts, during each half-hour of the charge, from the same quantity and quality of coal :—

	IRON RETORTS.	FIRE-BRICK RETORTS.
1st half-hour.	250 cubic feet.	180 cubic feet.
2nd ,,	630 ,,	1800 ,,
3rd ,,	1340 ,,	2000 ,,
4th ,,	2300 ,,	2000 ,,
5th ,,	2600 ,,	2300 ,,
6th ,,	2640 ,,	2300 ,,
7th ,,	2600 ,,	2460 ,,
8th ,,	2600 ,,	2400 ,,
9th ,,	1700 ,,	2000 ,,
10th ,,	1630 ,,	1630 ,,
11th ,,	1790 ,,	860 ,,
12th ,,	700 ,,	550 ,,
	Total 20780	Total 20780

The third requisite in a retort is *durability*. The proper way to measure this element is to divide the quantity of gas made by the cost of the retorts and ovens and the repairs during the time they are worked. This will be shown presently by a comparison from the actual working of iron and fire-brick retorts.

The retorts to be described in the present paper are composed entirely of fire-bricks, with cast-iron front plates to attach the mouth-pieces to, and to bind the brickwork together; and they are made of any length, width, or height. They are generally constructed in sets of three, as shown in Fig. 1, Plate 73, which is a front elevation. A A are the front plates of cast iron, $1\frac{1}{8}$ inch thick. B B are the wrought-iron stays, 4 inches by $1\frac{1}{2}$ inch, fastened at the bottom by cramps built into the brickwork, and at the top by tension bars connected to similar stays at the opposite end. C is the furnace door. D D are the two lower retort mouth-pieces, 15 ins. by 15 ins. E is the large upper retort mouth-piece. F F are sight-holes for examining the flues and cleaning dust from the external surface of the retorts.

Fig. 2 is a transverse section; G is the furnace, H H are the two lower retorts, 15 inches wide by 15 inches high and 20 feet long, with a mouth-piece at each end. The fire-bricks forming the bottoms and sides of the retort are 16 inches long and 3 inches thick, and the arch-bricks forming the top are 9 inches long by $3\frac{1}{2}$ inches deep. Each brick is rebated 1 inch deep in the transverse joints, and grooved in the longitudinal joints, as shown by the enlarged drawing, Fig. 3; these grooves are filled with stiff fire-clay when they are put together, which burns into a hard tongue $\frac{1}{2}$ inch thick as it becomes heated. The object of these tongues is twofold: they offer a resistance to the leakage of the gas by breaking the joint, and they tie together the arch of the retort.

K is the large upper retort, 5 feet 3 inches wide, and 20 feet long, open for charging at both ends; the bricks are similar to those forming the small lower retorts. L L are a series of cross arches, each 5 inches thick, spanning the furnace G, and flat on the top; these arches cover the underside of the transverse joints in

the bottom of the large retort K, while the longitudinal joints are covered by the small arched bricks I I. J J are the side flues, and N N the longitudinal flues, the latter being shown more fully in Fig. 5, Plate 74, which is a plan of the top of the upper retort K, showing the course of these flues. In rising from the furnace G the heat passes partly underneath and partly over the small retorts H H into the first flue, No. 1, and travels to the back of the oven; it then crosses the division and returns to the front along the 2nd flue, then to the back along the 3rd, and again to the front along the 4th flue, when it meets with the heat which has gone through a similar course on the opposite side, and passes along the middle flue, No. 5, into the main flue M, as shown in the longitudinal section, Fig. 4. By this arrangement the heat passes over 50 feet length of surface of retort from the time it leaves the furnace until it reaches the main flue.

Fig. 4 is a longitudinal section through the upper retort K, showing the opening into the main flue M, and the damper O by which the draught is regulated. In this figure is shown the position of the cross arches L L that carry the large retort K, covering the transverse joints in the bottom of the retort; also the centre wall P, which divides the two furnaces and flues and carries the main flue M.

Fig. 6, Plate 75, is a plan of the lower retorts H H, showing the two furnaces G G, with the centre division wall P, the side flues J J, and the floor of the lower retorts.

It will be seen by the plan, Fig. 5, that the sight-holes F F are so arranged as to command a view of the whole longitudinal and side flues, by which means the condition of the retorts may at all times be observed, and any defects detected.

With regard to the durability, the writer may observe that twelve sets of these retorts were put up by him in 1842, and worked constantly, with the exception of short periods, up to 1849, when they were taken down for the alteration of the works; and they were found then in good condition, and were fit for working several years longer with slight repairs. The writer also put up twelve sets of

these retorts in 1844, and they continue in regular work now, and are in good condition: the cost of repairs of the retorts, ovens, and furnaces during the eight years they have worked has not exceeded 20*s*. per annum for each set.

The writer accounts for the durability and economy of retorts constructed on this plan, firstly, by their being composed of a great number of pieces, instead of only one; so that when their temperature is altered, either by the carelessness of the stokers or in letting down the heat to throw the retort out of work, each joint opens a little, to an extent equal to the contraction of a 9 inch brick, and prevents any portion of the retort from cracking. In the same way, in getting up the heat (which is a time when a great number of clay retorts made in one piece are destroyed), if one portion of the retort becomes heated more than another, the joints accommodate the expansion. Or if the brickwork is in a very green state and the expansion from the moisture is great, the screws of the tension rods may be eased, which will allow the whole mass of brickwork to swell; but as soon as the moisture is expelled it will sink back into its place, and be as perfect as when first built. When a set of these retorts is first put to work, either new or after being let down for any purpose, it leaks through the joints for about 24 hours, gradually stopping; and after that time, if the heat be good, it will have become quite sound and permanently gas-tight, under a pressure equal to 10 or 12 inches head of water.

From a sufficiently long experience, the writer has proved that brick retorts built upon this plan will wear for 10 years, with the outlay of 20*s*. per annum for repairs, and that iron retorts will not last more than $1\frac{1}{2}$ years under the most favourable circumstances. Then to show their comparative economy, take a number, say 20 sets or beds of iron retorts, and 20 beds of fire-brick retorts, each bed being capable of making 20,000 cubic feet of gas in 24 hours; and to make the calculations as correct as possible, let the cost and repairs of each be estimated, and the quantity of gas they will make, during a period of 10 years, in order to ascertain the cost of the gas produced from each plan per 10,000 cubic feet.

	£	s.	d.	£	s.	d.
First cost of 20 beds of Iron Retorts:—						
Bricks, clay, and labour for arches	367	0	0			
100 cast-iron retorts, 18 cwts. each, 90 tons at £6...	540	0	0			
Fire-bricks, shields, quarries, etc., for setting ...	150	0	0			
Labour for setting, 60s. each bed...	60	0	0			
				1117	0	0
Cost of renewing 20 beds of iron retorts:—						
100 iron retorts, 90 tons at £6	540	0	0			
Bricks and clay	150	0	0			
Labour for taking down and re-setting	80	0	0			
	770	0	0			
Less by old burnt iron, 50 tons at 25s. £62 10 0						
Less by one third of bricks, which may be used again 50 0 0						
	112	10	0			
	£657	10	0			
This sum will be multiplied by 6½, the number of times they will be renewed in 10 years, which will give				4273	15	0
Making the total expense of Iron Retorts...				£5390	15	0

	£	s.	d.	£	s.	d.
First cost of 20 beds of Fire-brick Retorts :—						
Bricks, clay, and labour for arches	367	0	0			
Iron for front plates and brick-stays, 21 tons at £6...	126	0	0			
Pattern and other bricks, and clay, for retorts ...	180	0	0			
Labour for building retorts	110	0	0			
				783	0	0
Cost of repairs for 10 years, at 20s. per bed per annum	200	0	0			
Less value of old front plates, &c., 20 tons at 25s.	25	0	0			
				175	0	0
Making the total expense of Fire-brick Retorts ...				£958	0	0

Now as the quantity of gas that each of the two descriptions of retorts is estimated to generate is the same for 10 years, namely 1460 million cubic feet, it follows that the gas from the cast-iron retorts costs 9*d.* per 10,000 cubic feet, and that from the fire-brick retorts 1½*d.* per 10,000 cubic feet, for the item of retorts and ovens; showing an economy of 82 per cent. in the improved fire-brick retorts.

Mr. CLIFT exhibited specimens of the fire-bricks, showing the mode of jointing them to prevent leakage of the gas.

Mr. CHELLINGWORTH enquired whether a defect in a brick retort could be repaired, such as a bad joint. When an iron retort became broken it could not be repaired, and was all lost, and had to be pulled out; but it was a great advantage in the brick retorts if they could be readily repaired.

Mr. CLIFT replied that a defect could be easily repaired at any time, without stopping the working of the retorts; the surface of the retorts could be thoroughly examined through the different sight-holes, and any defective joint detected by the appearance of a gas flame, and a single brick could be taken out of any part when required, and removed by proper tools through the sight-holes, which were made large enough for a brick to pass; and another brick was then set in its place with fire-clay, without occasion to let down the heat of the retort. When a brick retort was pulled down, it was found that the carbon deposited from the gas filled up any crack or fracture, by the carbon adhering to the rough surface of the brick and collecting upon it, from the indestructible nature of the brick. But a crack in a cast-iron retort continued getting worse, and became constantly more open, on account of the surface of the iron perishing in the sides of the crack, which prevented it from getting closed up by a deposit of carbon as in the brick retorts. When a cast-iron retort was once cracked it was done for, and must be thrown away, requiring the whole oven to be opened out and rebuilt, and causing a serious delay to the work, as well as expense.

Mr. RAMSBOTTOM remarked that the greater equality in the rate of expansion by heat of carbon and fire-brick, than of carbon and cast iron, would probably assist in keeping the joints close.

Mr. CLIFT observed that on pulling down the brick retorts after seven years' working it was found that the joints were completely blackened and filled with carbon half way through, up to the fire-clay stopping in the centre groove; but the outer half of the joints showed no appearance of the carbon having passed the groove.

Mr. H. WRIGHT said he had lately had some gas ovens built on Mr. Clift's plan, instead of renewing the cast-iron retorts used previously, and they had been at work for some months very satisfactorily; there was no appearance of defect in getting up the heat or letting it down, and he considered that the plan was an important improvement.

Mr. CLIFT observed that the plan of constructing the retorts of double the usual length, with a mouth-piece at each end, he had only had in use for about a year; but he found it a decided improvement, and had since adopted it in all new works. The other retorts became scurfed up with a large accumulation of carbon, particularly at the back ends, where the scurf became several inches thick and very hard, and the retorts had to be stopped work and the heat let down, usually every eight months, for the purpose of clearing out this scurf, and getting it detached by the contraction in cooling. But in the long retorts, open at both ends, there was no back for the scurf to accumulate at, and the current of air through the retorts every time that both ends were opened caused the scurf to scale off, and it was much easier to detach: and consequently it was found that they would work much longer before requiring to be let down. Also the centre portion of the oven, which was the hottest part and most valuable for making gas, was lost before by the blank ends of the retorts, but was now made available, as there was only a single brick wall dividing the flues: and by this means the heating surface and content of the retorts were increased, without any increase in the size or expense. Another advantage was found in preventing the injury and shaking of the joints that was caused in drawing the coke from the retort, by the heavy rake being driven against the back of the retort.

The thanks of the meeting were voted to Mr. Clift for his paper.

The Meeting then terminated.

After the meeting a Model was exhibited of a new construction of Permanent Way for railways, by Mr. J. E. McConnell, of Wolverton.

PROCEEDINGS.

27 October, 1852.

The General Meeting of the Members was held at the house of the Institution, Newhall Street, Birmingham, on Wednesday, 27th October, 1852; Robert Stephenson, Esq., M.P., President, in the Chair.

The Minutes of the last General Meeting were read and confirmed.

The Chairman announced that, according to the rules of the Institution, the President, Vice-Presidents, and five of the Council in rotation, would go out of office next year; and that at the present meeting the Council and Officers for the next year were to be nominated for the election at the next Annual Meeting. He observed that he had always held that in such Institutions as their own it was highly conducive to their advancement that the officers be changed periodically, especially the President. He had taken an active part in bringing about the change in the Institution of Civil Engineers of the injurious system of Life Presidents, and since that change he had every reason to believe the result was very satisfactory. He had proposed to the Council to retire at this next election, having been President for four years, since the decease of his father; but as the Council had expressed a desire that he should be put in nomination for one year longer, he had consented, on the understanding that the proposed alteration should be then carried out, making the President ineligible for re-election after one or two years.

The Chairman announced that the Council proposed to submit to the Members, for decision at the next Annual Meeting in January, an increase in the number of Vice Presidents from three

to six, with reference to the different meetings of the Institution in Birmingham and other places. Nine names were proposed for nomination as Vice-Presidents, and if the proposed increase was adopted at the Annual Meeting, the six highest would be elected; otherwise the three highest, as before.

The following list of Members was then proposed for nomination, for the election of the Council and Officers at the next Annual Meeting:—

PRESIDENT.

* Robert Stephenson, M.P., . . . London.

VICE-PRESIDENTS.

(*Six or three of the number to be elected.*)

* Charles Beyer, ... Manchester.
William Fairbairn, ... Manchester.
Edward Humphrys, . . . London.
Edward Jones, ... Liverpool.
* James E. McConnell, . . . Wolverton.
* John Penn, ... London.
Robert B. Preston, . . . Liverpool.
Archibald Slate, ... Dudley.
Joseph Whitworth, . . . Manchester.

COUNCIL.

(*Five of the number to be elected.*)

Samuel H. Blackwell, . . . Dudley.
* William Buckle, ... London.
* John E. Clift, ... Birmingham.
Benjamin Fothergill, . . . Manchester.
Wyndham Harding, ... London.
John Napier, ... Glasgow.
Richard Peacock, ... Manchester.
* J. Scott Russell, ... London.
* Robert Sinclair, ... Glasgow.
* Joseph Whitworth, . . . Manchester.

TREASURER.

* Charles Geach, M.P., . . . Birmingham.

SECRETARY.

* William P. Marshall, . . .	Birmingham.

(*The Officers for the present year are marked thus* *.)

No other names having been added by the Meeting, the above list was adopted.

The Chairman announced that the Ballot Lists had been opened by the Committee appointed for the purpose, and the following New Members were duly elected:—

MEMBERS.

Samuel Lloyd, Jun., ...	Wednesbury.
Henry Rofe, ...	Birmingham.
George Thomson, ...	Birmingham.
John R. Warham	Burton-on-Trent.

The following paper by Mr. Samuel H. Blackwell, of Dudley, was then read:—

ON THE ARRANGEMENT OF THE MATERIALS IN THE BLAST FURNACE, AND THE APPLICATION OF THE WASTE GASES.

The use of the Waste Gases given off from the top of the Blast Furnace has been long known and adopted in many of the Continental ironworks. The higher cost of fuel, and the greater attention paid to a scientific knowledge of the most important processes of manufacture, led to the use of the waste gases of the blast furnace in the works of France and Germany, long before their application here; the United States soon followed the example of the Continent, and in the ironworks of Pennsylvania for some years past the use of the waste gases has been general. The object of this paper is to point out some of the causes which have prevented their more general use in England in our great ironworks; and to call attention to some light thrown, by the attempts to use them, upon the best arrangement of the materials in the furnace.

The first attempt to apply the gases in our ironworks was at Ystalyfera in South Wales by Mr. Budd. The method of employing them was at first defective, from the direct flame of the furnace being taken off, instead of the gases themselves. The moment the gases emerge from the top of the furnace and unite with the atmosphere, ignition takes place; and if the flame is to be economised, it must be immediately applied to the surface upon which it is to act, or its heating power is given off and consequently wasted. The attempt therefore to apply *flame* necessitated the erection of the boilers, or of the pipes in which the blast was to be heated, in immediate contiguity with the tunnel head. In many works this was a matter of great difficulty, and in very few could it be done without inconvenience. Even where practicable, the flame always acted powerfully upon the passages through which it passed, and exhausted itself in proportion to their length and absorbing powers, before it became available at the points where it was really required. This difficulty led to such an alteration in the arrangements adopted, that instead of the *flame* the *gases* themselves could be drawn off from the materials in the furnace, before they had become ignited by mixing with air.

This was effected by the arrangement shown in Fig 1, Plate 76. A cylinder A of cast or wrought iron, resting by a broad flange upon the lining of the furnace, was carried down to a depth of several feet beneath the top of the pipe B, through which the gases passed off. The diameter of the furnace expanding from the top downwards, an open space C C was thus enclosed between the cylinder and the inside wall of the furnace, forming a reservoir for the gas, into which, as long as the cylinder was kept full, no air from above could enter. This arrangement perfectly answered its purpose, as far as regarded taking off the gas unignited; and although it still passed off at a high temperature, the loss of heat in the passages was much diminished, being confined to simple radiation from the hot but unignited gas: however far it was carried its chemical nature remained unchanged, and atmospheric air was allowed to mix with it only on its reaching the point where the heat given off in its combustion became available.

All difficulty in placing either the boilers or the pipes for heating the blast was thus obviated; but there remained two sources of inconvenience. First, a very powerful draught was required to be given by a sufficient height of stack to draw off the gases with regularity; and second, the entire quantity which it was possible to draw off under the most favourable circumstances bore only a small proportion to the total quantity generated in the furnace, the greater part of which still escaped through the open cylinder.

Where a powerful stack was at hand, and where it was not a matter of importance to economise the entire amount of gas generated, this arrangement was in many instances satisfactory. It was not always so however; in many works it was found impossible to get the furnaces to work well after the gases were taken off: great fretting of the tuyeres, accompanied by frequent scaffolding and slipping in the furnace, was constantly producing irregularity in its working; the quantity made would thus be much decreased, and after much annoyance the attempt to use the gases was in such cases generally abandoned, as productive of more inconvenience and loss than economy.

This was much more the case in South Staffordshire than in Wales. In the former district it led, after three or four trials, all with the same result, to the complete abandonment of the plan. It was difficult to understand the cause of this great irregularity in the results obtained, which at first seemed inexplicable; but this cause is now believed to be fully understood.

In the year 1849 two furnaces in Derbyshire were placed in the writer's hands, from which the gases were taken off for the purpose of heating the blast. The furnaces worked with considerable regularity whenever the heat could be properly maintained; but this was not constantly the case, in consequence of the opening into the gas flues being situated so near the top of the furnace that, when the wind was in certain directions, the gas did not pass off with regularity, or if it came off in sufficient quantity, it was so mixed with atmospheric air that it burned down the passages, and thus occasioned great inconvenience.

The writer determined upon obviating this by covering the opening into the gas flue with a wrought-iron cylinder, as in Fig. 1. The tops of the furnaces were small, and only admitted of cylinders of the respective sizes of 4½ feet and 6 feet being employed. The effect was perfectly satisfactory in enabling a regular supply of unignited gas to be obtained; but the furnace with the 4½ feet cylinder began to scaffold and slip; the tuyeres were exceedingly troublesome, and the weekly make fell off considerably. After a trial of one or two weeks, the cylinder was taken out, other means were adopted to prevent the gas taken off from becoming ignited, and the furnace again resumed its former regularity. The furnace into which the 6 feet cylinder had been placed worked far better, but not quite satisfactorily; and upon the cylinder burning out, it was not replaced, arrangements being made similar to those adopted in the other furnace. It will not be necessary to describe the exact details of these arrangements, as arrangements similar in principle but improved by subsequent experience will be afterwards described; they did not differ much from those shown in Fig. 6, Plate 78. Both furnaces have worked ever since satisfactorily, and the gases taken off furnish all the heat required for heating the blast, no slack whatever having been used for some years for the purpose.

It was evident from this trial, and from similar results at other works, that the irregularity did not arise from the mere abstraction of the gases themselves; and there was only one other cause to which it could be attributed, namely the narrowing of the filling part of the furnace. The question then arose, in what way did this operate. The first suggestion that presented itself was naturally that the effect produced arose from decreasing the area through which the gases generated in the furnace were given off, and thus causing greater obstruction to the free passage of the blast. This explanation was soon found to be untenable.

The saving effected in some of the Welsh works by the use of such a portion of the gas as could be economised by means of the cylinders employed there led to a wish to make the entire quantity

of gas generated available, by closing the top of the furnace, and not allowing any gas to escape into the open air.

This was first effected by Mr. Levick at the Cwm Celyn Works. The arrangement adopted by him is seen in Fig. 2, Plate 76.

Two cast-iron bearers A A (one of which only is visible in the section) are placed across the furnace, at a depth of about 7 feet below the top; upon these a cone of cast iron B is placed, the base of the cone being less than the diameter of the furnace. A short cylinder C, about 3½ feet deep, is suspended from the filling plate, resting by a flange upon the lining of the surface, as in the case of the cylinders previously used; and a second cylinder D of about the same depth rests upon the base of the cone. This second cylinder being larger than the first, and being moveable around it, can be lifted up by means of two bars of iron or chains attached to it, passing through openings made for the purpose in the flange of the upper cylinder. E is the pipe for the passage of the gases. When the lower cylinder rests upon the cone, as shown in the diagram, the top of the furnace is closed in entirely, and the space inside the two cylinders can be filled with the materials constituting the charge. Upon lifting up the lower cylinder, the charge immediately falls into the furnace round the base of the cone; and the cylinder being again lowered, the top is once more closed in. By this arrangement all the gases can be economised, and far greater heating power obtained.

Another arrangement effecting the same purpose was soon afterwards adopted at the Ebbw Vale Works. This is seen in Fig. 3, Plate 77.

Here an inverted and truncated cone A is fixed in the top of the furnace, resting on the lining by a flange similar to those employed to suspend the cylinders. The truncated end is closed by another cone B, the apex of which ascends through the truncated end of the upper cone and closes it. This closing cone is suspended by a chain, by which the cone can be lowered or raised at pleasure. C is the pipe for the passage of the gases. The lower cone being raised up, the furnace top is closed, and the materials are wheeled into the upper cone; the moveable cone is then lowered, and the

materials at once drop in around it. This arrangement is now in full operation and working satisfactorily at several of the works belonging to the Ebbw Vale Company.

Both at these works, and also at the Cwm Celyn Works, the furnaces with the closed tops work well; they carry equal if not better burdens than those which are open; they work with equal regularity, and make an equal quantity of iron. The area through which the gases are taken off is in some cases not equal to that of a 3 feet pipe, and much less than that of the smallest of the cylinders which produced such unfavourable results. Consequently the injurious action of these cylinders could not arise from the decreased vent permitted to the gases, nor from any obstruction in the blast. The only other way in which the cylinders could produce any effect would be by causing the materials filled into the furnace to fall too much towards the centre of the furnace; thus producing an arrangement which in some way acts prejudicially upon its general working. By the action of the cones, the materials filled into the closed furnaces are scattered round the side of the furnace, and are thus arranged as they would be in open furnaces with wide tops. It thus became at once obvious that cylinders in Wales had been productive of less injurious consequences to the general working of the furnace than those in Staffordshire, because the greater width of the Welsh tops had permitted cylinders of from 8 to 10 feet to be employed, whilst in Staffordshire only cylinders of much smaller size were practicable.

The important effect produced on the working of the furnace chiefly by an alteration in the arrangement of the materials in the furnace is a point of considerable interest, but one to which little attention has been hitherto paid. In practice it has long been known to the best managers of furnaces that wide tops were desirable, and generally accompanied by increased make; but the precise manner in which wide tops acted was not clearly known until the attempt to use the waste gases led to its evident explanation. On the Continent the importance of such an arrangement of materials as would facilitate the passage of the

blast as nearly towards the centre of the furnace as practicable has been known for some time and acted upon; and the writer was much pleased to find from M. Tunner, professor of metallurgy in Austria and connected with the Styrian ironworks, that great increase of make had followed the adoption of wide tops in the charcoal furnaces of that district, combined with a method of filling whereby the coke or charcoal was placed in the centre of the furnace and the ore and limestone around the sides.

Some few months back a furnace was placed in the writer's hands, which he found provided with a cylinder and other arrangements for taking off the gases. Although apprehensive that the cylinder would materially interfere with the working of the furnace, yet, as everything was arranged for it and as it was 6 feet in diameter, he determined to blow the furnace in without alteration. This was done, and the expected result followed: constant slipping, and fretting tuyeres, with all their attendant bad effects. The stacks were not powerful enough to draw off the gases unless a closed top was used, and the writer therefore adopted an arrangement somewhat similar to the Ebbw Vale one last described; the exact fittings and arrangement are shown in Fig. 4, Plate 77. The result was immediate; the furnace worked with great regularity, and carried a good burden, but white iron alone was produced. The burden was lightened, but the iron remained white. A yet further lightening of the burden was made, but although the cinder was exceedingly grey, still the iron was white. It became evident that a greater proportion of coke would not produce the desired change, and was in fact useless. The white iron was evidently the effect of the closed top. A pipe of 9 inches diameter was inserted at the filling place, but with no effect. Another pipe was inserted, and some little change appeared. As it was important to produce grey iron, it was now determined to sacrifice the use of the gases entirely, rather than continue to make white iron. The lid or valve A upon the main gas pipe B, and also the covering E of the gas pipe CC, were therefore opened, and a decided change was at once evident. The iron became grey, and the furnace worked with regularity. The white iron had

evidently been caused by the pressure produced by the closed top; and so extremely sensitive did the furnace appear to be to the slightest restraint upon the free removal of the gases, that even a strong wind blowing into the open box, through which the gases were principally escaping, would throw the furnace to white iron.

In Wales, where the closed tops are successfully employed, the production of white iron is rather sought for, and hence the tendency in closed tops to produce that quality is no disadvantage. In many cases however it must be a fatal objection to their use. But for this objection closed tops would become universal, as they entirely do away with the necessity for a lofty stack, and enable all the gases to be economised.

That the tendency to produce white iron had no connection with the mere abstraction of the gases from the furnace is clearly shown by the results of the Scotch furnaces, in which they are taken off without employing closed tops. At Dundyvan especially, great attention has been paid to this point, and the result has shown that the furnaces from which the gases are taken off work with equal regularity and produce grey iron with equal facility to those from which the gases are not taken off; and it would be easy to multiply instances of the same result.

The manner of taking off the gases at Dundyvan is shown in Fig. 5, Plate 78. The furnace is 42 feet high, and 12 feet diameter in the centre; it commences to narrow at 12 feet from the bottom to form the boshes and hearth, the hearth being 7 feet wide at the bottom; it also commences to narrow at 8 feet from the top, which at the filling plate is 8 feet wide. Below the part so narrowed, eight flues AAA, 4 feet high and 18 inches wide, placed at equal distances from each other, lead into an annular chamber BB running round the furnace and continued up to the filling plates, by which it is closed; the pipe C for the passage of the gas is placed nearly at the top of this annular chamber. Sometimes the entrances to the flues are covered by a wrought-iron cylinder, 10 feet wide, resting on a flange let into the lining of the furnace at a depth of from 5 to 6 feet below the filling plates, so as to leave a circular

space between the cylinder and the lining of about 12 inches width. The cylinder is not shown in the diagram. Although this arrangement works satisfactorily, it is doubtful whether the cylinder is necessary, and indeed it is more than probable that it would be destroyed before the furnace had been long in blast.

In many furnaces with open tops, from which the gases are now taken, the use of the cylinder has been abandoned altogether as needless. In such cases however it is quite necessary that the openings into the flues should be at a sufficient depth from the top of the furnace, to prevent the possibility of the admixture of atmospheric air with the gases. To ensure this, a depth of 10, 12, or even 15 feet is sometimes adopted with advantage. The gases pass off more readily at these depths, in consequence of the greater resistance of the superincumbent materials; and they are in a more suitable state for heating purposes. Fig. 6, Plate 78, shows the arrangement adopted for taking off the gases at a furnace recently erected at Pontypool, in which it will be seen that the use of the cylinder is abandoned.

In reference to this latter point, it is necessary to consider briefly the composition of the gases, and the chemical changes taking place in the furnace. The most able investigations of the nature of the gases of the blast furnace are those of M. Ebelmen, and almost all the knowledge we possess of their chemical composition will be found in a paper communicated by him to the "Annales des Mines" in 1851, which contains not merely a summary of M. Ebelmen's own investigations, but also an examination of those of Messrs. Bunsen and Playfair as reported to the British Association.

From M. Ebelmen's experiments it would appear that the first action of the blast upon its entrance into the furnace through the tuyeres is to produce carbonic acid, by the union of the oxygen of the atmosphere with the carbon of the coke; this is accompanied with the intense heat required for the fusion of the iron ore. The carbonic acid as it passes upwards is converted into carbonic oxide, by contact with the carbon of the incandescent coke above the zone of fusion. As the carbonic oxide ascends higher in the furnace it

acts as a reducing agent upon the oxide of iron of the ore, by uniting with the oxygen, by which a considerable portion is again converted into carbonic acid. The gases emerging from the top of the furnace are therefore, from the result of the chemical action now detailed, and also from the carbonic acid liberated from the limestone used as flux, more highly charged with carbonic acid than those which may be taken off at a lower point; and consequently, to the extent of this greater proportion of carbonic acid, they possess less heating power. Where only a portion of the gases are taken off therefore, as in the case of open tops, the depth of the flue is important in reference to the quality of the gas taken off, as well as to its freedom from any admixture with atmospheric air.

In this notice of M. Ebelmen's experiments, all attention to the composition of the gases, except in reference to their heating power, is purposely omitted.

The results at which we may now be said to have fully arrived are the following:—

1st.—That the waste gases may be used with great economy in raising steam and heating the blast.

2nd.—That they must be taken off in such a manner as to prevent their mixing with atmospheric air before they arrive at the place where they have to be applied.

3rd.—That this may be effected in two ways: either by placing the openings for taking them off sufficiently below the surface of the materials in the furnace, or by closing the filling part entirely.

4th.—That the first plan is the most desirable where grey iron is requisite, but where adopted it is necessary that a powerful draught should be obtained by a sufficiently lofty stack.

5th.—That when thus taken off the gases can be conveyed to any distance proportionate to the power of draught available, without losing any of their calorific power beyond that lost by simple radiation; the whole of the calorific power to be obtained from their combustion being economised, until atmospheric air is admitted to them at the point where the heating effect is required.

6th.—That no arrangement of the filling place should be permitted which narrows that part to less than 8 feet diameter; from 9 to 10 feet, according to circumstances, being generally the most advantageous dimension.

The CHAIRMAN remarked that it was a very important and interesting subject, and well deserving the consideration of ironmasters. He observed that no heating power, except the actual temperature of the gases, would be lost by the distance of conveying the gases away from the furnace to the place where they were ignited for use; and he enquired whether it had been ascertained what was the temperature of the gases where drawn off from the furnaces.

Mr. BLACKWELL replied that it was not accurately known, but it would not be very considerable, as the gases were not ignited. In one mode of carrying out the principle that was adopted in France, the gases were actually passed through water after leaving the furnaces, to separate all impurities and injurious matter, and also to prevent any risk of explosion. In that case also the only heat lost would be the temperature of the gases in coming from the furnace before they were ignited.

Mr. BENJAMIN GIBBONS remarked that it had been first established by his late brother, John Gibbons, that the size of the aperture at the top of the furnace should be considerably increased over the old practice; the upper aperture he increased from 4 feet to 9 feet, and he (Mr. B. Gibbons) had tried it even 10 feet diameter; from 8 to 9 feet was found the best size, and was indispensably necessary in the South Staffordshire district.

Mr. BLACKWELL said that when the top of the furnace was closed he had found, in every instance that he had tried, the production of white iron; closed tops seemed always to produce that result.

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4th.—That the first plan is the most desirable where grey iron is requisite, but where adopted it is necessary that a powerful draught should be obtained by a sufficiently lofty stack.

5th.—That when thus taken off the gases can be conveyed to any distance proportionate to the power of draught available, without losing any of their calorific power beyond that lost by simple radiation; the whole of the calorific power to be obtained from their combustion being economised, until atmospheric air is admitted to them at the point where the heating effect is required.

6th.—That no arrangement of the filling place should be permitted which narrows that part to less than 8 feet diameter; from 9 to 10 feet, according to circumstances, being generally the most advantageous dimension.

The CHAIRMAN remarked that it was a very important and interesting subject, and well deserving the consideration of ironmasters. He observed that no heating power, except the actual temperature of the gases, would be lost by the distance of conveying the gases away from the furnace to the place where they were ignited for use; and he enquired whether it had been ascertained what was the temperature of the gases where drawn off from the furnaces.

Mr. BLACKWELL replied that it was not accurately known, but it would not be very considerable, as the gases were not ignited. In one mode of carrying out the principle that was adopted in France, the gases were actually passed through water after leaving the furnaces, to separate all impurities and injurious matter, and also to prevent any risk of explosion. In that case also the only heat lost would be the temperature of the gases in coming from the furnace before they were ignited.

Mr. BENJAMIN GIBBONS remarked that it had been first established by his late brother, John Gibbons, that the size of the aperture at the top of the furnace should be considerably increased over the old practice; the upper aperture he increased from 4 feet to 9 feet, and he (Mr. B. Gibbons) had tried it even 10 feet diameter; from 8 to 9 feet was found the best size, and was indispensably necessary in the South Staffordshire district.

Mr. BLACKWELL said that when the top of the furnace was closed he had found, in every instance that he had tried, the production of white iron; closed tops seemed always to produce that result.

Mr. Slate had been informed that at the Middlesbrough works in the North of England much stronger iron than they required for castings was produced by closing the tops of the furnaces, though not quite white iron, but a high number of pig; and that a considerable reduction of make was the general result.

Mr. Gibbons said that a plan which would answer in one district might not succeed in another district, on account of the great difference in the quality of the ores.

Mr. McConnell noticed that it was stated in the paper that a greater proportion of carbonic oxide was found at one height than at another; and he enquired whether any experiments had been made to ascertain the height from which the gases should be taken off in order to get the best result.

Mr. Blackwell replied that from 12 to 15 feet below the top was the greatest depth that he was aware of such a trial having been made. Carbonic acid was generated at the bottom, as the product of combustion, in the neighbourhood of the tuyeres; after rising towards the centre of the furnace the carbonic acid became converted into carbonic oxide, by taking up carbon from the mass of incandescent fuel, and carbonic oxide prevailed there; but higher still the carbonic oxide reduced the iron ore, and much of it became carbonic acid again. At the top of the furnace there was a considerable proportion of carbonic acid, with a portion of carbonic oxide, but in the centre of the furnace there was carbonic oxide alone.

Mr. Slate enquired whether, if only carbonic oxide existed in the centre of the furnace, any experiments had been tried for drawing off the gases from the centre instead of taking them from the top.

Mr. Blackwell did not know of any experiments having been made for taking the gases from the centre of the furnaces, and he believed that 15 feet from the top was the lowest that had been tried; but it must be observed that in all probability if the gases were drawn off at a lower level it would reduce the yield of the furnace, because the carbonic oxide was required to reduce the ore of the metal, and it would take away so much of the reducing power of the furnace.

Mr. SLATE remarked that the practical effect would then be to shorten the furnace, and work with a very short furnace, which was known to be bad. He suggested that perhaps the reduced make of furnaces with closed tops was due to the reduction of the quantity of air entering at the tuyeres, on account of the resistance to the discharge from the top of the furnace being increased, which would tend to diminish the quantity of air blown in by the same blast engine.

Mr. BLACKWELL did not think that was the case, as it was not always the consequence that the yield was reduced by closing the top of the furnace; at Cwm Celyn a rather greater yield was found with a closed top to the furnace than when open. It must be borne in mind that, from the different composition of the ores in different districts, the plan might succeed in one case when it would not in another.

Mr. GIBBONS remarked that the Staffordshire ore required a double proportion of limestone compared to the Scotch ore, and therefore more carbonic acid was generated in the blast furnace.

The CHAIRMAN enquired whether any experiments had been made relative to the actual economy produced by the employment of the waste gases.

Mr. BLACKWELL replied that at the Ebbw Vale Works they were raising the steam for the blast engines entirely by the waste gases from the furnaces, and also heating the blast; and from 15 cwts. to 1 ton of coal would otherwise be wanted for that purpose per ton of iron made.

The CHAIRMAN asked whether the plan was found to cause any injury to the boilers or the heating pipes for the blast.

Mr. BLACKWELL said the action was found less destructive to the boilers than the ordinary fire, because the heat was very uniform, and the boiler was not exposed either to fluctuations in temperature or to excess of heat.

Mr. SLATE observed that the saving of the consumption of slack in South Staffordshire would amount only to 6d. per ton upon the iron, owing to the small cost of the coal usually burnt under steam boilers.

Mr. Blackwell said that of course there was a great difference in the value of slack with different qualities of coal; in South Staffordshire, from the slack not having a caking quality, it could be used only for steam boilers and inferior purposes; but in South Wales most of the refuse slack was a valuable material for making coke, which increased its value very much, and made the saving an important consideration.

Mr. W. Mathews enquired what would be the effect on the heating pipes, assuming that the action on the boiler was less prejudicial. There might be a difference perceived in the effect of the action of the gases on the pipes and on the boilers in different districts, from the variation in the quality of the materials.

Mr. Blackwell replied that he had had the plan in operation for three years in some furnaces in Derbyshire, and during that time no instance had occurred of repair being required for the hot-air apparatus; but it had to be opened about every six weeks to clear away the deposit of dust. He understood however that at the Dundyvan Works a considerable loss of heat appeared to be caused by the thick coating of the pipes with dust.

Mr. W. Mathews remarked that he had lately been over the Dundyvan Works in Scotland, where the gases had been applied more extensively than elsewhere, and was informed by the manager that he considered they would be as well without this plan, as they found it had a very prejudicial effect on the heating pipes, though less perceptible on the boilers. In Wales they appeared to be using the plan with considerable advantage, on account of the greater price of fuel and coal slack. In South Staffordshire he thought it doubtful whether it would be found advantageous; a very slight interference with the regular working of furnaces would be a serious prejudice both to the quality and yield of iron, and would more than counterbalance any economy arising from the application of the gases. He believed that at no other works in Scotland had the plan been persevered in, except at the three or four furnaces at Dundyvan. At the Gartsherrie Works it had been tried and abandoned.

Mr. Gibbons said that after he had made preparations for the trial of the plan he came to the conclusion that nothing material

was to be saved by the adoption of it but 15 cwts. of slack per ton of iron, costing him only from 1*s.* to 1*s.* 6*d.*, and therefore he had not proceeded in the trial of the plan; he had only proposed to try it for the boilers and the hot blast.

The CHAIRMAN enquired what was the nature of the dust that was found to collect so rapidly on the pipes of the hot blast apparatus.

Mr. BLACKWELL replied that the chemical character of the dust was not at present well understood, but that the effects alluded to by Mr. Mathews arose simply from the mechanical action of the very large quantity of minute dust given off from the furnace, which could not be cleaned from the surface of the heating pipes so well as from the surface of the boilers, the draught not being sufficient to prevent it from being deposited on the surface of the pipes.

Mr. SLATE observed that a great quantity of coke dust and ore was carried off by the blast from the contents of the furnace.

Mr. McCONNELL enquired whether the dust could not be removed by drawing the gases through a screen of wire-gauze, so as to filter the air before entering the hot-blast apparatus.

Mr. BLACKWELL replied that the passage for the air from the furnace should be as free as possible, and the wire-gauze would cause too much obstruction. In the French works that had been referred to, the air was carried through water to stop all dust and impurities, which appeared to accomplish the object successfully.

The CHAIRMAN asked whether Mr. Blackwell agreed with M. Ebelmen's theory of carbonic acid being first produced, then changed to carbonic oxide, and lastly partly converted to carbonic acid again, higher up in the furnace. He could not understand such a process.

Mr. BLACKWELL said he did not consider himself competent to give any opinion upon the chemical changes occurring in the furnace: he considered the theory a probable one, especially as it appeared to be fully confirmed by M. Ebelmen's experiments, in which the gases were taken off at different heights of the furnace, and subjected to careful analysis.

The Chairman said he could not think that the carbonic oxide took up an atom of oxygen from the oxide of the metal; it was a law of chemical affinity that the second atom combined with less force than the first. He considered it much more probable that an atom of carbon was taken from the carbonic oxide to unite with the iron. He did not think that the carbonic oxide could de-oxidise the iron, and he could not understand the two converse processes taking place at the same time in the furnace.

Mr. Blackwell said that in the Exhibition, accompanied by M. Le Play (one of the Jurors of the Exhibition, and professor of metallurgy in Paris) and Professor Faraday, he saw some curious specimens called "metallic sponge," which were formed of pieces of iron ore, exposed when heated to a current of carbonic oxide or carburetted hydrogen, which de-oxidised them. M. Le Play was acquainted with the process before, but it was new to Professor Faraday, who was much interested with the specimens. He (Mr. Blackwell) had not seen the process of de-oxidation, but was informed that it was effected by both means, either by carbonic oxide or by carburetted hydrogen.

The Chairman proposed a vote of thanks to Mr. Blackwell for his important and valuable communication, which was passed.

The following paper, by Mr. William A. Adams, of Birmingham, was then read:—

ON IMPROVEMENTS IN THE CONSTRUCTION AND MATERIALS OF RAILWAY WAGONS.

The improvements described in the present paper consist principally in the substitution of wrought iron for wood in the construction of the under-frame of Railway Wagons.

In the commencement of 1851 the attention of the writer was directed to the construction of a large number of wagons for the conveyance of coal, which were to be hired for a term of years, and in which consequently the desideratum to be aimed at was such

a construction as should commercially be the least costly in maintenance, and at the same time the most lasting in ultimate duration, with due regard to first cost. Experience had shown that, without large and costly repairs and replacements, the life of an ordinary wood under-frame does not exceed a much longer period than ten years; whilst at the same time the experience of the Great Western Railway had proved that iron under-frames, when properly constructed, continue after many years' work in excellent condition.

In a former paper (see Proceedings Inst. M. E. January 1851) the writer brought before the Institution the question of the substitution of wrought iron of various sections in the place of wood, in the construction of the rolling stock of railways, with the view to economise weight. A careful consideration of the subject, with the practical and scientific aid of Mr. W. P. Marshall and Mr. E. A. Cowper, has enabled the writer to produce wagons with iron under-frames and stanchions, of a simple construction, and at the same time at only a trifling excess in cost as compared with the usual wood-framed wagons. These wagons have been in daily work for twelve months, and about 500 of this construction are now working on the Taff Vale Railway, the Monmouthshire Railway, and the London and North Western, and the Midland Railway; and so far as experience shows at present, they are more economical in maintenance than the usual wood-framed wagons, and give promise of a longer life. The experience of these wagons has suggested improvements in some of the minor details of construction, but none in the main points.

The Wagon to be described in the present paper is of a somewhat different class, as the wagons first constructed were adapted for discharging coals at a shipping port by tailboard doors, and the present wagon discharges the coal at the side; but the construction of the under-frame is essentially the same. The tare or dead weight of this wagon, to carry 6 tons, with ordinary wheels and axles, is 2 tons 19 cwts.; and the tare of ordinary wagons of precisely the same class, constructed by the writer with the same wheels and springs, is 3 tons 6 cwts.; the iron-framed wagon being 11 per cent.

lighter. It is to be observed that at the present time there is no possible commercial inducement to the private wagon-owner to reduce the dead weight, but every inducement to reduce the first cost, with due regard to maintenance and durability; and consequently no attention has been given to the reduction of the weight in the details of construction, whenever such reduction of weight entails any additional trouble or cost.

The construction of the improved wagon is shown in Plates 79 and 80. Fig. 1 is a side elevation of the wagon; Fig 2 an end elevation; Fig. 3 a plan of the under-frame; Fig. 4 a transverse section of the wagon; Fig. 5 a longitudinal section of the end of the wagon; and Fig. 6 a section of the centre cross-bearer. Fig. 7 shows enlarged sections of the frame-iron A, the cross-bearer C, and the stanchions H, specimens of which are exhibited; the smaller section of frame-iron D is used for a smaller class of wagon.

The soles AA and headstocks BB are constructed of the larger frame-iron, which is 8 inches deep, $4\frac{1}{2}$ inches wide on the bottom flange, and 13-32nds inch thick; the weight is 20 lbs. per foot. The section of the frame-iron is designed according to the principle discussed in the former paper, so as to obtain with the least weight of material the greatest amount of strength under the particular circumstances to which it is subjected; the mass of metal in the section is situated at the three extreme points, vertically and horizontally, to afford the greatest strength, and the ends are thickened to 11-16ths inch at the top and 13-16ths at the bottom. This frame-iron is rolled in a similar manner to ordinary angle-iron. The corners of the frame are mitred, being sawn cold by a machine set at an angle of 45°, which ensures truth in the joint. On the under side the corners are secured by a plate 5 inches wide by $\frac{3}{8}$ inch thick, fixed with three $\frac{3}{4}$ inch rivets at each end. The top of the frame-iron is secured by a knee $2\frac{1}{4} \times \frac{5}{8}$ inch, fixed with three $\frac{5}{8}$ inch rivets on the side, and two at the end. Below this the corner is further secured by an angle-iron knee $3\frac{1}{2} \times \frac{1}{2}$ inch, fixed to the side with two $\frac{5}{8}$ inch rivets, and to the end with one rivet, the other hole taking one of the bolts of the buffer-block. A

little draw is given to all the rivet holes, by which means the two pieces of frame are forced together at the corner, making a secure and rigid joint.

The cross-bearer C in the centre is made of T iron, 6×3 inches and $\frac{5}{8}$ inch thick; it is notched at the ends, to fit over the bottom flange of the frame-iron, to which it is secured by two $\frac{3}{4}$ inch rivets through the bottom, and an angle iron knee at the side. The cross-bearer and headstocks, where weakened in the centre by boring for the draw-bar, are flitched on each side by two $5 \times \frac{1}{2}$ inch plates.

The diagonals DD are of fir, 11×3 inches, laid flatways; their outer ends abut against a piece of 2 inch angle-iron, rivetted to the headstocks, and they rest upon the lower flanges of the frame-iron and of the cross-bearer in the centre, being packed with fir packing to bring the upper side of the diagonals flush with the under side of the floor.

The floor E is of fir, $7 \times 2\frac{1}{2}$ inches, laid longitudinally, and it is fitted tight inside the frame, flush with the top of the frame-iron, abutting against the thickened top edge of the frame, so as to form a very strong and rigid bracing to the frame. The floor rests upon fir packings at the ends and centre, and is spiked down to the four diagonals. It is to be observed that one important advantage in this method of flooring is that the floor forms an entire panel, bracing the under-frame in all directions, and materially assisting the end resistance of the frame at the buffer-blocks.

The buffer-blocks FF are of elm, and fixed by three $\frac{3}{4}$ inch bolts, with heads inside, and nuts recessed in the face of the buffer-block, for the convenience of tightening up when they loosen in work.

The axleguards GG are two pieces of plate $\frac{5}{8}$ inch thick, and fixed with four $\frac{3}{4}$ inch rivets through each leg. The fixing of these guards being made with short rivets, measuring but 1 inch length between the heads, produces a perfectly firm job; and none of them have been found to loosen in work, with the exception of one or two cases where the rivet heads have broken off from imperfect workmanship or material.

The wagon is mounted on the improved springs SS that were brought before the Institution by the writer in a former paper

(see Proceedings Inst. M. E. January and April 1850), which reduce the total weight 148 lbs. in the set of four springs, and the expense proportionally, with the same extent of elastic action as the ordinary springs. The spring shoes are of cast iron, fixed with a $\frac{5}{8}$ inch bolt to the bottom flange of the frame iron, and prevented from turning round by a lip at the back, fitting against the frame.

The stanchions HH to support the ends are made of tramway iron, $3\frac{1}{2} \times 2$ inches, and are fixed to the frame by two $\frac{3}{4}$ inch rivets. A small cross-bearer of hard wood is fixed between the frame and the diagonal, to carry the side knee.

The construction of an ordinary wood-framed wagon, of the same size and class, is shown in Figs. 8, 9, and 10, Plate 80. Fig. 8 is a side elevation, Fig. 9 a cross section, and Fig. 10 a plan. The soles AA and headstocks BB are of oak, $12 \times 4\frac{1}{2}$ inches, mortised together, and secured by transverse bolts through the entire frame. The floor is laid crossways upon the soles. With the same height of buffers this wagon carries the load $6\frac{1}{2}$ inches higher than the iron-framed wagon.

The objects aimed at in the construction of the iron-framed railway wagon described above are—first, increase of durability, and consequent economy in the expense of maintenance, by the substitution of iron for wood in those parts that are subjected to constant strains and concussions, tending to rack the joints and make them work loose. In wood framing this action exposes it to great injury, from wet penetrating the joints; and the wood is liable to be shaken and split. But in the iron framing the joints are fitted, iron and iron, with very short bolts and rivets, and are as rigid and durable as boiler work; and the iron, when protected from oxidation by paint or tar, is of great durability, remaining nearly as sound as at first, after such a number of years' work as is the ordinary limit of the work to be got out of a wood frame.

The second object is diminution of weight in the frame, and consequent economy in the dead weight to be conveyed and the expense of locomotive power. This reduction of weight amounts to 11 per cent., and the resulting economy is an important consideration,

as a proportionate increase of load can be conveyed at the same expense of locomotive power; but at the same time it must be remarked that this point has, from commercial reasons, received but little or no attention at present, and the weight of construction is capable of much further reduction.

Mr. McConnell considered the wagon that had been described was an important step in the right direction, both as regarded durability and reduction of weight; he had suggested some time since to Mr. Adams the consideration of a reduction in the dead weight of railway wagons, having had experience of the cost of dragging the present great proportion of dead weight. He thought the construction adopted by Mr. Adams was very good, and that he had arrived at a good practical section of angle-iron: indeed the very best section next to a tube. Economy in dead weight was a very important subject; and this Institution, by such papers, might effect great economy in the expenses of railway working, by reducing the dead weight to be conveyed. He considered that much more might be effected in that respect than was commonly supposed.

Mr. Adams observed that his attention had first been drawn to iron framed wagons by trying to reduce the weight; but in the present wagon his only object had been to obtain greater economy in durability and expense of maintenance, without exceeding the ordinary expense of construction.

Mr. H. Wright remarked that he had many thousand wagons at work on the North Staffordshire and other lines, a number of them iron-framed, though mostly wood-framed, and he found that there was a greater expenditure in the repairs of the iron-framed wagons. The greatest increase of expense was mainly in the failure of the bolts that fixed the axleguards, which got sheared off by the sharp edges of the iron plate, from the rough usage to which the wagons were subjected in shunting about at stations; but

in wood-framed wagons the elasticity of the wood saved the bolts from breaking with a sudden blow. The wagons got very seriously injured by the blows that the wheels received by being run against the stops fixed at the ends of sidings; and this made the fixing of the axleguards an important matter. He quite agreed with Mr. Adams that it was a great advantage to reduce the dead weight.

Mr. E. Jones thought that one of the greatest sources of injury in knocking about wagons on railways was the want of spring buffers; they should all have spring buffers at one end, and the extra expense would be amply returned by the saving of injury in wear and tear.

The Chairman said he agreed in the opinion that all railway stock should have spring buffers; it would cause a great saving in the expense of repairs, and greatly increase the durability of the wagons; but if there was only one end of each with buffers, the two dead buffers would often be liable to get together, which would be as bad as having no spring, and the principle could not be completely carried out without spring buffers at both ends.

Mr. Slate thought that railway wagons should not be required to be built for running off the line. It was an important point to railway companies to avoid running off the line and the knocking about of wagons at the stations, and such bad usage should be prevented. A saving in dead weight would have the advantage of diminishing the injury in accidents, if combined with equal strength.

Mr. Adams enquired whether, in the iron-framed wagons mentioned by Mr. Wright (in which the axleguard bolts were found to shear off), the axleguards were not of the old shape, fixed on only with three or four $\frac{3}{4}$ inch screw-bolts, in which case the nuts working loose would make them liable to break off. He had not found any proof of deficient strength in all the number he had made, in which four $\frac{3}{4}$ inch rivets were employed to hold each leg of the axleguards.

Mr. H. Wright replied that in some cases only four screw-bolts were used, but they broke off without the nuts coming loose. The best form of axleguard for the purpose, he thought, was that shown

in the wood-framed wagon (Plate 80), which had two side arms, giving great support by the extended leverage.

The CHAIRMAN remarked that that certainly was the best form of axleguard, and it would be best for the iron-framed wagons also, which would make a good job. It was certainly a most important point to reduce the dead weight, but at the same time the wagons must be made strong enough to stand running off the line, so as to diminish the length of delay in case of accidents; all running stock must be strong enough to bear accidents. He proposed a vote of thanks to Mr. Adams, which was passed, and expressed a hope that this course of improvement would be still further pursued.

The following paper, by Mr. Paul R. Hodge, of London, was then read :—

ON A NEW SELF-LUBRICATING AXLEBOX FOR RAILWAY ENGINES AND CARRIAGES, AND A SELF-ACTING SPRING CROSSING POINT.

No part of the machinery of a railway requires constant lubrication more than the axle journals of locomotives, tenders, and carriages; as the heating of one journal in the whole train is sufficient to produce the most serious results, not only by delaying the traffic, but also by endangering the lives of the passengers in the train. Notwithstanding the great attention that this point has received, scarcely a train passes over our roads (in the summer more particularly) but some one or more of the axle journals heat. In one instance that the writer experienced, the whole train had to be passed into a siding for more than two hours, before it could again proceed on its journey. Through what he had experienced of the difficulties attendant on the use of grease as a lubricator, and from what he knew of the use of oil in the United States, he was induced to write to the inventor of the best Lubricating Axlebox in that country, knowing that the difference of cost of lubricating

was more than one half in favour of oil, with a proper axlebox. On application to Mr. J. E. McConnell, of the London and North Western Railway, a trial of the axlebox was at once made on some of the carriages of that line.

On no railway in the United States is grease used as a lubricator; many plans have been brought out in that country for axleboxes, but the one now brought before the meeting seems to be preferred, and is universally adopted. The average distance that carriages run there before any additional oil is supplied to the boxes, or before the journals and brasses are examined, is 8000 miles. This fact has been fully corroborated by the working of these boxes on the London and North Western Railway. The first boxes were put on the tender of No. 182 engine, which was immediately put on to the most trying work, during hot weather, sometimes running express trains at the highest speeds, and at other times on the worst possible work, ballasting; and yet after running 6000 miles in four months, without any additional oil, the journals and brasses were in as perfect a condition as when new.

This axlebox is shown in Plates 81 and 82. Fig. 1 is a longitudinal section; Fig. 2 a transverse section; Fig. 3 a front elevation; and Fig. 4 a back elevation.

A is the axle, B the journal; CC a wrought-iron collar, shrunk on the axle, having a groove turned in it to receive the leather flange DD, which is shown separately in Fig. 5. EE is the brass bearing, and FF the upper chamber, which is filled full of cotton waste, flax, sponge, or any other capillary material, to retain and pass the oil up to the journal. G is the lower or secondary chamber, for the reception of the dirty oil which finds its way down the space at the back of the bridge wall, with a tap screw at the bottom to let out the oil. H is an iron plate, bolted to the back of the box, to keep the leather flange D to its place. I is a covering plate bolted on the front of the box; this is the only opening into the box, besides the hole K for supplying oil, which is closed by a screw.

The results of the trial of the new axleboxes in the tender No. 182, upon the London and North Western Railway, have been officially reported to Mr. McConnell by his assistants as follows.

The axleboxes have run 5743 miles up to 20th September last; the bearings have been examined, and are found in a very satisfactory state. No oil has been supplied since the first day of running, four months previously; 10 quarts of oil have been supplied to the boxes altogether, and 5 quarts have been drawn off during the time from the bottom chamber, which is still good oil for screwing, drilling, and other ordinary work; the oil remaining in the boxes is considered sufficient, without more being added, to run at least from 3000 to 4000 miles more. The journals and brasses are wearing beautifully, with faces as though polished in the lathe; and a great advantage is found, that the great wear endways does not take place on the brasses, as in the ordinary boxes using yellow grease or tallow. The cost of lubrication is greatly reduced, as appears from the following account of the comparative consumption of the above tender with the new axleboxes, and another tender exactly similar, except that it was fitted with old boxes on Normanville's plan using tallow, both tenders having run the same distance, 6000 miles, under the same circumstances of trains, and the weather being dry and dusty nearly the whole of the time.

NEW AXLEBOXES.

	s.	*d.*
Oil put into the boxes at starting, 10 quarts at 9*d.*	7	6
Credit by 5 quarts drawn off from the bottom chamber, at 6*d.*	2	6
Actual cost of oil	5	0
Cotton waste, 4 lbs. at 2*d.*	0	8
Leathers, 4½ at 1*s.*	4	6
	10	2

Actual cost per day, 1·54*d.*, or ... 1½*d.* per day.

OLD AXLEBOXES.

Tallow required per day, 2 lbs. at 4½*d.* ... .. 9*d.* per day.

Saving per day on the 6 New axleboxes ... ... 7½*d.* per day.

	Cwt.	Qrs.	Lbs.
Weight of the 6 Old axleboxes ...	3	1	0
Weight of the 6 New axleboxes ...	1	2	20
Saving in weight of the 6 New axleboxes	1	2	8

The advantages of this axlebox over those now in use are:—

Firstly, the perfect exclusion of dirt or grit from the box, by means of the leather and wrought-iron collar.

Secondly, the certainty of constant and never-failing lubrication to the journals and brasses by means of the capillary medium placed in a separate chamber, and detached from the back of the box by means of the bridge wall, so that the level of the oil can be carried much higher than the joint of the leather and collar, allowing the upper chamber to be full of oil if necessary, while it is impossible that any oil can leak out at the back.

Thirdly, the provision of a secondary or under chamber for the dirty oil to drop into, from which it is drawn off, refined, and again returned to the upper chamber; or it is used in the machine shop for drilling, cutting bolts, and many other purposes, for which it is as good as new oil.

Self-acting Spring Crossing Point.—This crossing point, commonly called the Frog Point, is generally used on the railways of the United States. It is unnecessary on the present occasion to detail to practical engineers the difficulties and danger experienced in running engines and carriages at high speeds over the present crossings. It will be sufficient to describe the improved crossing point, which is brought before the meeting as a remedy for the evils attendant on the crossings now used.

Fig. 6, Plate 82, is a plan of the simplest construction of the spring crossing, and Fig. 7 a transverse section. AA is the main-line rail, and BB the cross-line, the crossing point C being the same as usual, but the wing rails DD are each moveable on a stud at the end, acting like switches, and two pins EE are fixed to them on the under side, passing through slots in the bedplate F. An india-rubber ring GG is passed round these pins, which draws them together, and keeps the moveable tongues DD in close contact with the crossing point; so that the rail presents an uninterrupted surface for the trains running through either line, the flanges of the wheels opening the tongue on the opposite side, which closes again directly they have passed.

Fig. 8, Plate 83, is a plan of another construction of the crossing, and Fig. 9 a transverse section. In this the india-rubber springs GG

act as buffer springs, being put upon a horizontal spindle H, which passes through the two studs EE on the moveable tongues DD, and has a washer at each end to confine the india-rubber buffer springs, so that they are constantly pressing the moveable tongues against the fixed crossing point.

The main feature in both of these arrangements is that they afford a complete uninterrupted tread for the wheel whilst passing through the crossing, at the same time ensuring a certainty of action in whichever direction the train is passing. The only difference between the two buffer springs and the round ring of india-rubber is that the former are compressed and the latter distended; but either plan is found to work with certainty, and the india-rubber spring is found to be very durable.

Mr. McConnell said that he believed the statement in the paper was correct about the results of the trial he had made of the axlebox. There was a perfect exclusion of dirt from the journal, and the keeping it constantly in contact with the oil was an important advantage. He was satisfied they must ere long abandon grease for oil; there was a great loss of power from defective lubrication of the carriage and wagon journals in cold weather, as no lubrication took place on first starting until the journals got heated, and then they were liable to get too hot, and the grease ran away, and was scraped off the outside of the boxes and put in again mixed with grit at the stations. Oil was generally ready for action in any weather, and he thought railway companies must ultimately adopt oil for all moving journals, particularly with the present increase in the speed of trains and the weight on the working bearings.

Mr. Lea, of London, mentioned a new material for lubrication that he was bringing into application; it had been tried some years since by Mr. Ramsbottom, with very satisfactory results; but further trials had been suspended till now, from difficulties of the inventor who was now dead. This lubricating substance consisted

of a peculiar semi-fluid composition, applicable to the present axleboxes; oil was the basis of the composition, but thickened with india-rubber and other materials; it had an affinity for the iron bearing, which prevented the displacement of the material from the rubbing surface. The manufacture of the material was not expensive, costing only 4*d.* per lb.; and when charged at 16*d.* per lb. it had been found in the trial made that there was a very considerable saving in the cost of lubrication compared with the ordinary grease or tallow. He wished to make a further trial of it on railways, and thought it would prove an important improvement. There was a great advantage in this plan, from its requiring no change in the present axleboxes. No ordinary pressure in the bearings could squeeze out the lubricating material; therefore it remained between the surfaces, preventing contact, and consequently preventing any heating by friction.

The CHAIRMAN said they would be glad to have the results of a further trial of the new lubricating material, and to receive more particulars at the next meeting.

Mr. E. JONES observed that the use of a spring crossing point was not new in this country; it had been in regular operation for six years on the Great Western Railway, and also on the Bristol and Exeter and the South Wales lines; and fourteen years ago he remembered something of the kind in use on the Hartlepool Railway. He had made several hundreds for those lines with flat steel springs, originally of his own invention, at Bridgewater. A $2\frac{1}{2}$ feet spring was used for crossings of 600 feet radius, and a $3\frac{1}{2}$ feet spring for 900 or 1000 feet radius, according to the curve. The springs were $2\frac{1}{2}$ inches wide and $\frac{3}{4}$ inch thick, tapered to 3-16ths inch. He gave a sketch of the spring crossing (see Plate 83, Figs. 10 to 14). He had tried some with india-rubber springs, but did not find these so lasting as steel springs, which were all adopted. The steel springs were found to answer the purpose very satisfactorily, and no objection to them had been experienced in working. They were very durable. There had been some instances of springs breaking, but they were very easily replaced. The crossings were made safe in any case, even though broken, by the tongues being prevented

from rising or getting wrong even if the bolt broke or came out, as the moving tongue was bound down by strong clips at each end.

The CHAIRMAN said he remembered that on the Stockton and Darlington Railway spring crossing points were tried at one time, but were abandoned, from getting knocked to pieces with the increase of speed and weight in the engines. He was not aware before of their general use in America. He doubted their permanent durability and use where there was a large traffic.

He thought the axlebox described in the paper was a very successful application of oil, and was very likely to accomplish an important desideratum in the satisfactory employment of oil instead of grease, as oil was undoubtedly a much more correct material for lubrication.

Mr. ADAMS enquired what was the result found in the working of Normanville's and other oil-tight grease-boxes. He observed that an axlebox had been brought out some years since by his father for a similar purpose, with a leather collar to prevent the waste of grease or oil.

Mr. H. WRIGHT said that Normanville's first axlebox was intended to feed in front, with the supply of grease below the journal, and filled up close to it. But the grease was found to lose its nature and get hard below the journal; and the box was then improved by keeping the grease in a chamber above, as in the ordinary boxes. He had known several kinds of oil-boxes, but they were all liable to the spilling of the oil from side blows and oscillations. The employment of the cotton waste in the axlebox described in the paper he thought was decidedly a good plan to prevent the oil from spilling over; and he enquired the result that had been found in the trial on the London and North-Western Railway.

Mr. McCONNELL replied that there appeared to be no spilling or loss of oil, and the dust and grit were effectually kept out of the box. The oil drawn off from the bottom chamber was very black and thick, and not suitable to use again in that state, though it might be fit for drilling purposes, &c.; but after being properly purified, it was very good for lubrication again. There was a bridge

at the back of the axlebox, just high enough to prevent the oil from flowing off; the oil did not come into contact with the leather joint, which was only to prevent the entrance of grit and dust.

Mr. E. Jones said he remembered that on the North Union Railway, many years ago, Mr. Williams had tried a collar or picking-up ring on the middle of the journal, which dipped into cotton waste saturated with oil whilst revolving, continually picking up a supply of oil for lubricating the journal.

Mr. Chellingworth remarked that there was a plan of lubrication with a cork ball about 1 inch diameter; two of these balls floated on the surface of the oil, rolling against the journal to distribute the oil. He believed it was a French invention, but did not know the result of its application.

Mr. McConnell said he was not acquainted with that plan. The leather in the new axleboxes was not found to wear away, and appeared likely to last a long time, as there was no pressure or strain upon it; the leather was not bent, but simply fitted easily into the groove in the iron collar, which was shrunk on the axle.

Mr. H. Wright observed that the leather would probably wear the iron away before it was worn away itself; he had found it necessary in Normanville's axlebox to increase the surface of contact by a longer bearing of the leather collar on the axle, to allow for the wearing away of the iron by the constant grinding action with the particles of grit.

Mr. Allan remarked that he had used sponge in the axleboxes of engines for the last ten years, and found the results very satisfactory. They found that the consumption of oil, which was previously 6 to 8 quarts for the 100 miles trip between Birmingham and Liverpool, was now reduced to 1 quart, partly by the introduction of sponge in the axleboxes of the ten bearings of the engine and tender. The plan still continued very successful, and they had adopted it generally in their engines and tenders.

The Chairman enquired whether the sponge was placed below, to catch the oil falling from the bearings; and whether the oil was fed from above as usual.

Mr. Allan said that was the mode of application; the sponge wiped up the oil, thus preventing the loss of the oil that would have dropped from the journal, and keeping the journal constantly oiled smoothly over.

Mr. McConnell thought that sponge would be liable to get hard with a hot axle, and that the cotton waste would be a better plan. In the new axlebox the great improvement, he considered, was in having the reservoir of oil below the journal instead of above; that appeared to be the best mode of application, as any grit or impurities in the oil settled to the bottom, and were prevented from coming in contact at all with the journal by that arrangement, but this could not be entirely prevented when the reservoir was above the journal. The lower separating chamber for the waste oil was also an important improvement, keeping up a constant gradual separation of the impure oil, and affording a great means of economy in using the oil over again, after being purified. The leather collar was a very effective and simple contrivance to exclude the grit and dust, which were a great source of expense and injury in the ordinary axleboxes.

Mr. Slate asked what was the comparative economy of the American axlebox and Mr. Allan's plan. In the latter plan 1 quart of oil was consumed for 100 miles, but in the other there was said to be 5 quarts for 6000 miles, or 1 quart only for more than 1000 miles.

Mr. Allan remarked that the 1 quart of oil which he had mentioned was used for all the bearings, moveable joints, &c., of the engine and tender, not for the axleboxes alone as in the trial of the new axlebox; and he had no means of knowing what proportion of the whole was consumed by the axle journals.

The Chairman asked Mr. Allan to give a sketch of his sponge axlebox, with an experimental trial on the consumption of oil in the axleboxes alone, independent of the rest of the engine.

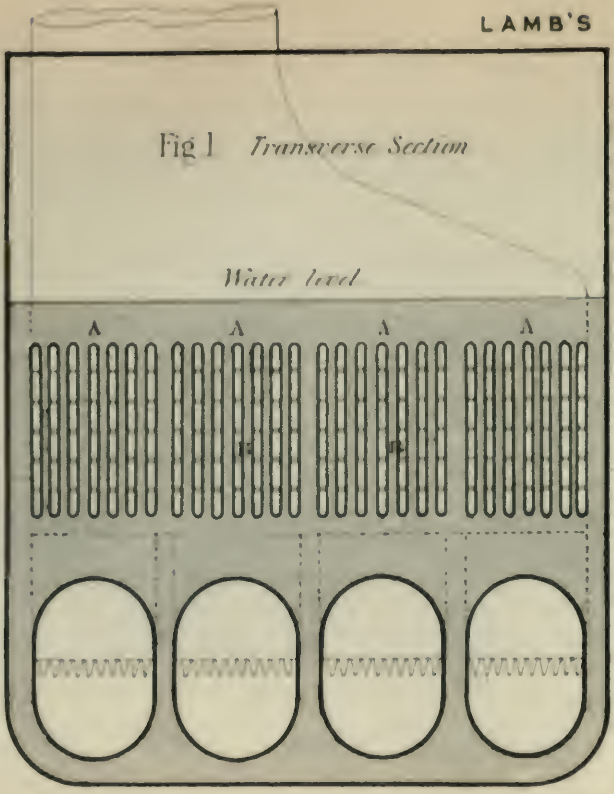
Mr. Allan said that he would give it at the next meeting of the Institution, and would try for a week or two the actual consumption of oil in the axleboxes, to ascertain the proportion as far as was practicable.

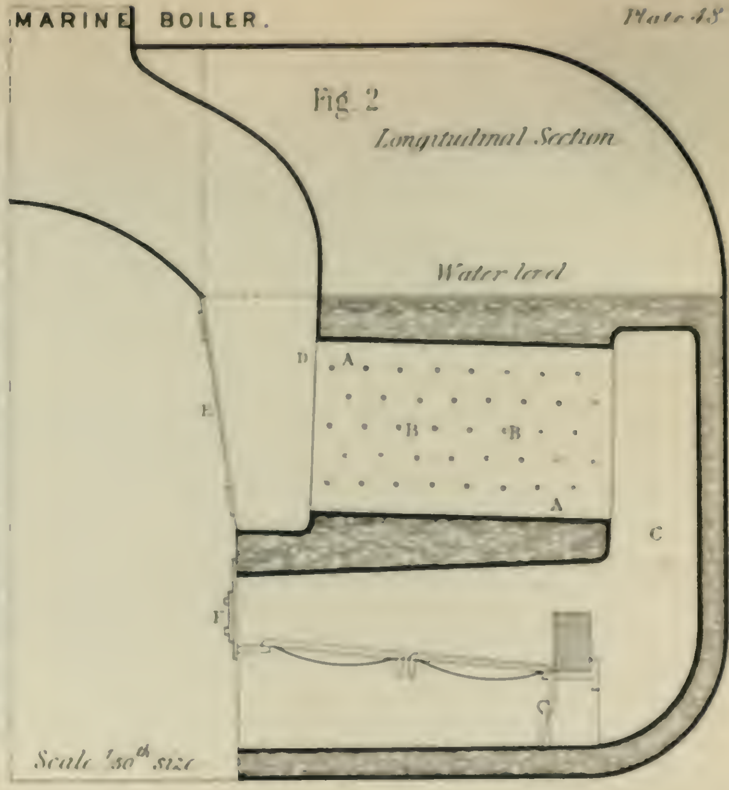
Mr. Forsyth, of Wolverton, remarked that one circumstance had not been mentioned in the description of the new axleboxes tried on the London and North Western Railway; the cotton was rammed in tolerably tight from the front, filling the boxes up solid except against the ends of the axles. The cotton was put in dry, and it became gradually saturated by pouring in oil from time to time at the top hole; it would continue to absorb oil for several days. The surface of the cotton waste, when examined after running the 6000 miles, was like a metallic polished surface next the journal, but still it was found saturated with oil close up to the surface of contact. The leathers were cut straight up $\frac{3}{4}$ inch from the axle, but not bevilled, to get them into the groove of the iron collar; but no leakage was found to take place, as the cotton was not over-saturated, and the oil never came in contact with the leather so high up as the cut.

The Chairman proposed a vote of thanks to Mr. Hodge for his paper, which was passed, and expressed a wish for further information about the results of trial of the axlebox.

The Meeting then adjourned; after which specimens were exhibited by Mr. J. McConochie, of Wednesbury, of a new Permanent-way Chair for Railways.

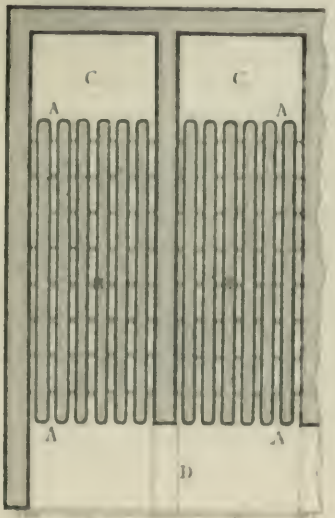
LAMB'S MARINE BOILER.





LAMB'S MARINE BOILER.

Fig. 3
Plan of Boiler



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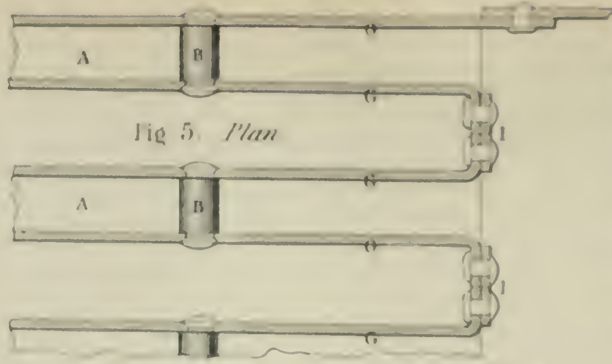


Fig 5. *Plan*

Details of Flues

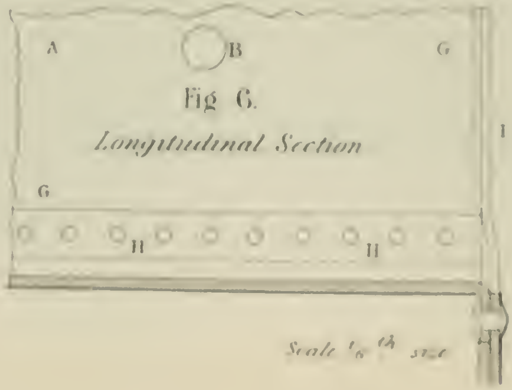


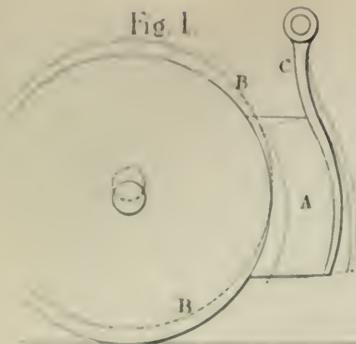
Fig 6.
Longitudinal Section

Scale [illegible] size

Fig 1.
Vertical Section

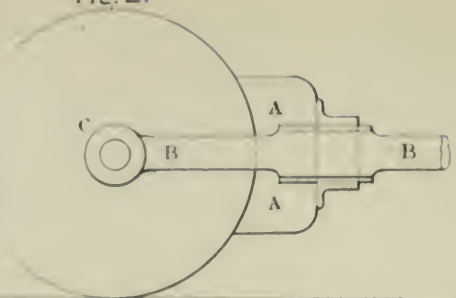
RAILWAY CARRIAGE BREAKS.

Fig. 1.



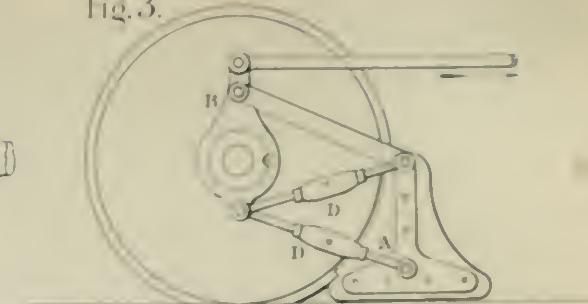
Hanging Break

Fig. 2.



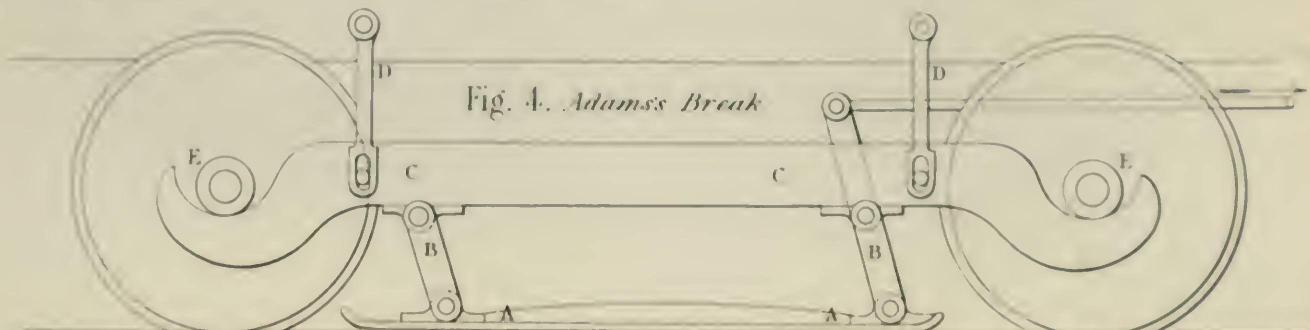
Sliding Break

Fig. 3.



Lees Break

Fig. 4. Adams's Break



Scale 1/24th size

RAILWAY CARRIAGE BREAK.

Fig. 5.

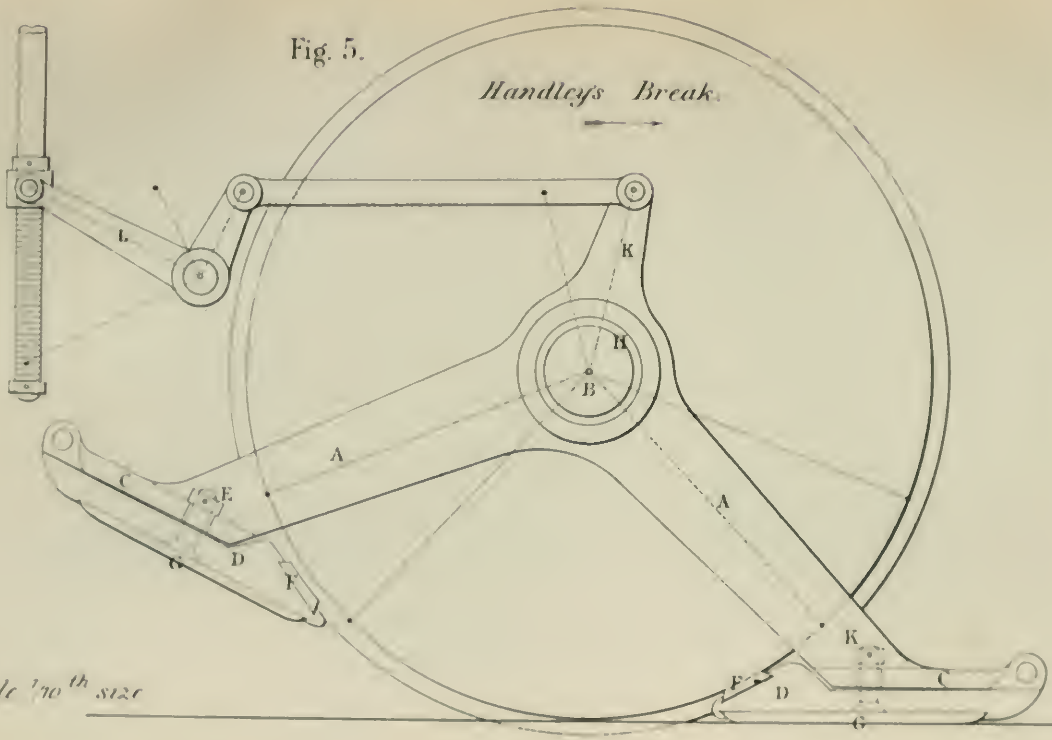


Fig. 6.

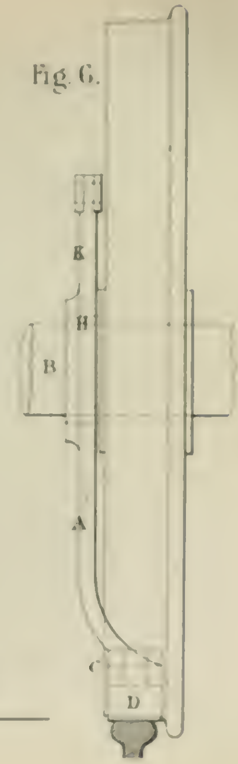


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Plate 51

SAMUEL'S
CONTINUOUS EXPANSION ENGINE.

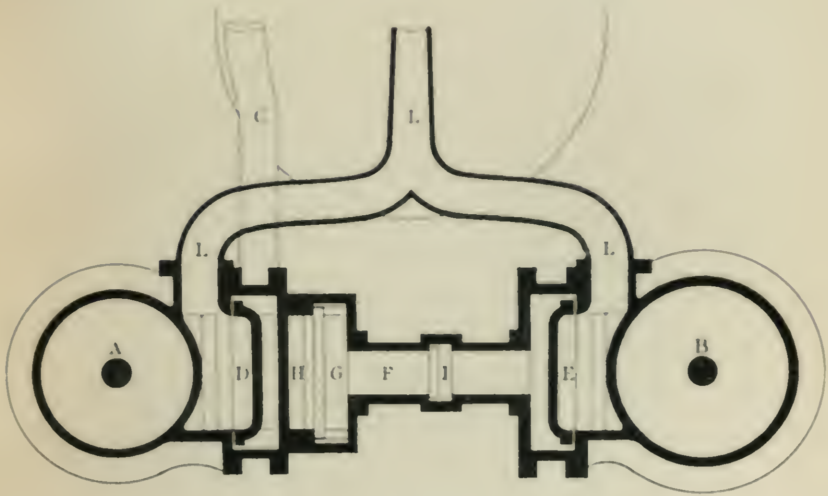
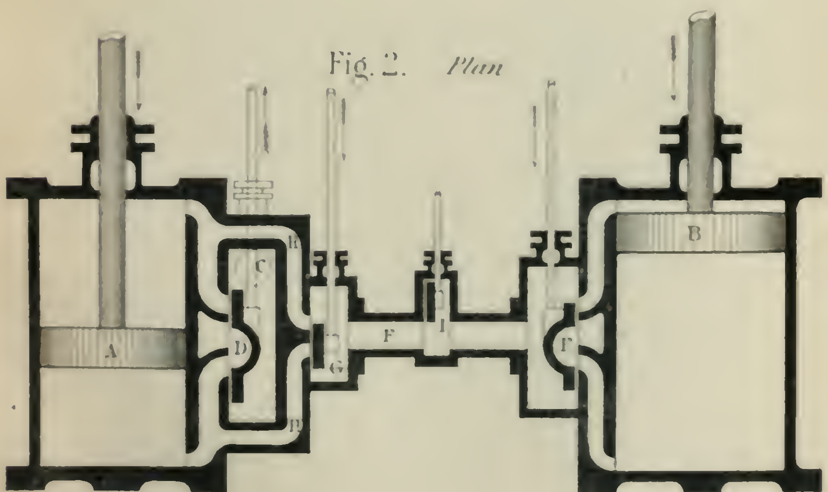


Fig. 1. *Vertical Section*

Fig. 2. *Plan*



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CONTINUOUS EXPANSION ENGINE.

Diagrams showing the Variations in Rotative Moving Power during one half revolution of the crank

Fig. 3
Cornish Engine

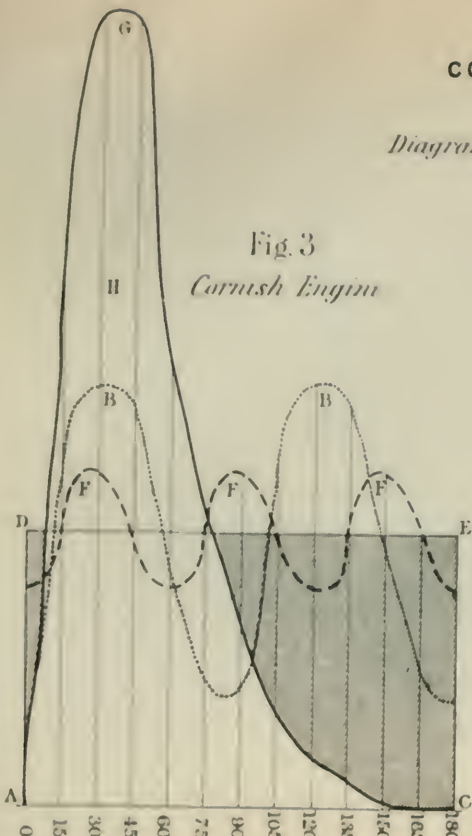


Fig. 4.
Continuous Expansion Engine

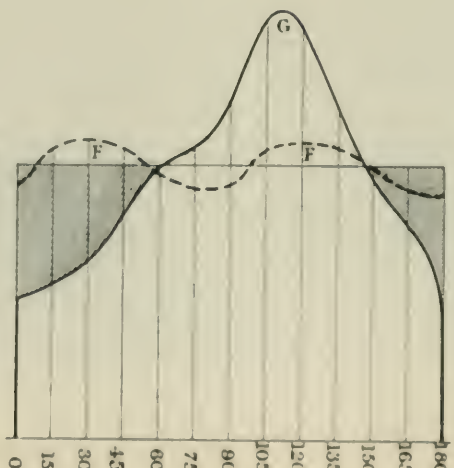


Fig. 5
Woolf's Engine

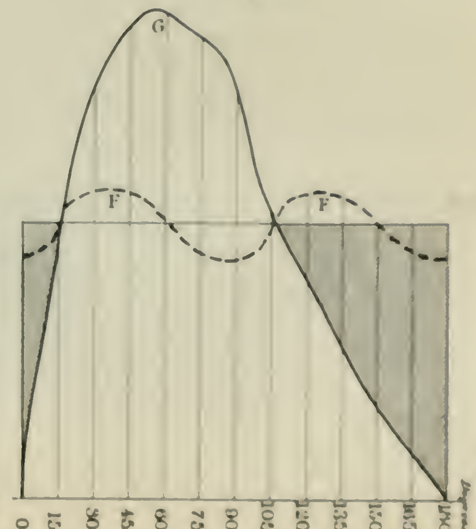


Plate 53.

CONTINUOUS EXPANSION ENGINE

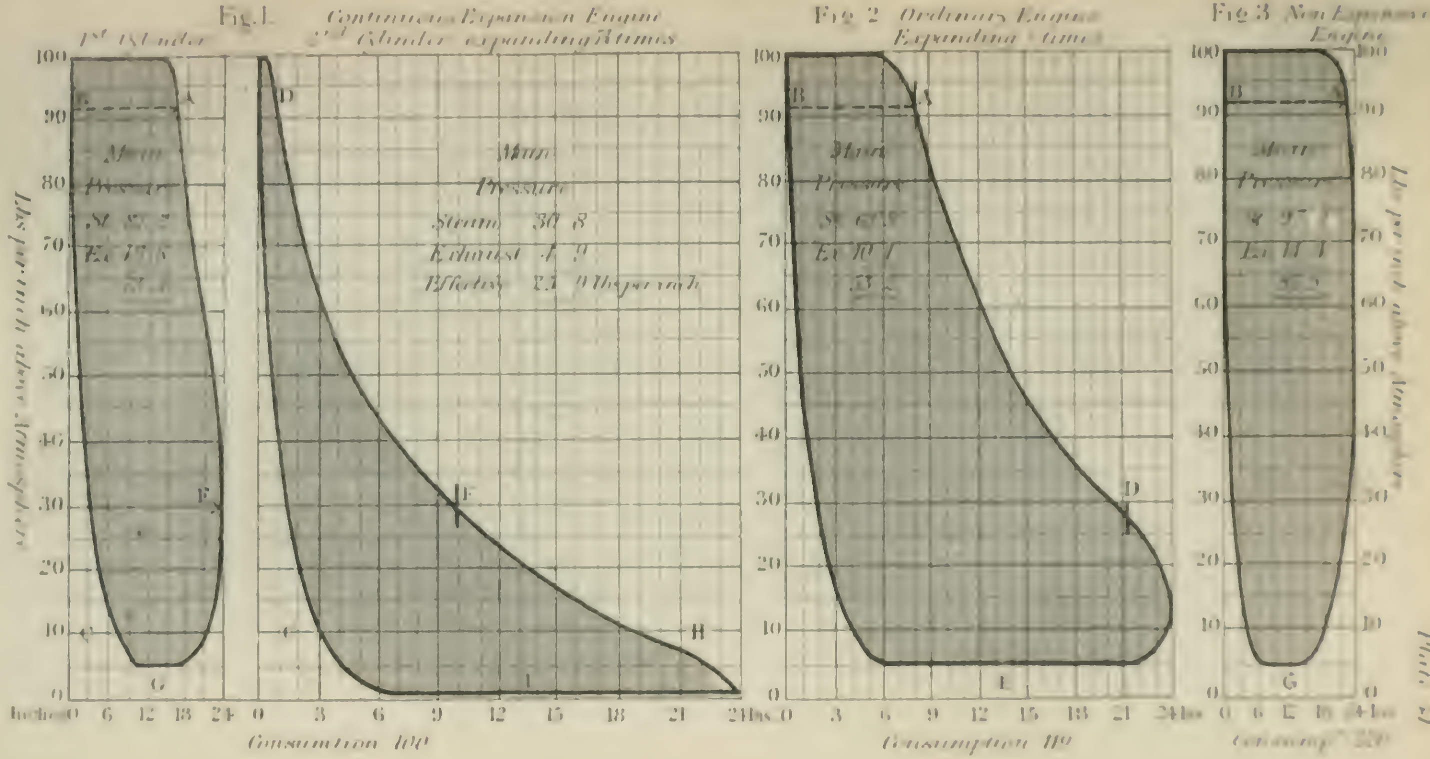


Fig 2 *Plan*

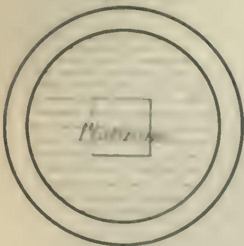
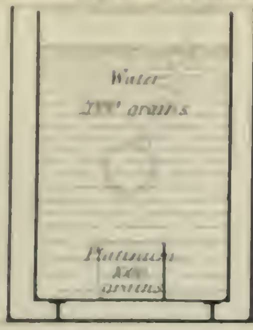


Fig 3 *Thermometer*



Scale ½ size

Fig 4

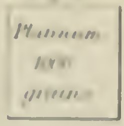
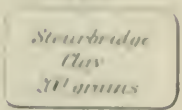


Fig 5



Full Size

EXPANSION OF STEAM.

Fig 1 *Indicator Diagrams with very slow motion from Caledonian Locomotive N° 15*

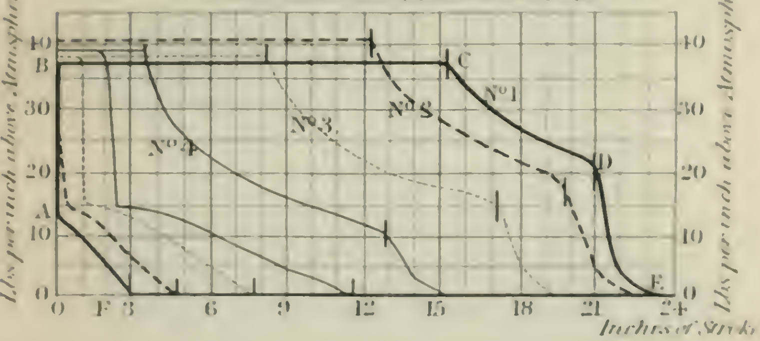


Fig 6 *Diagram of the actual consumption of Steam Per Horse power per hour*

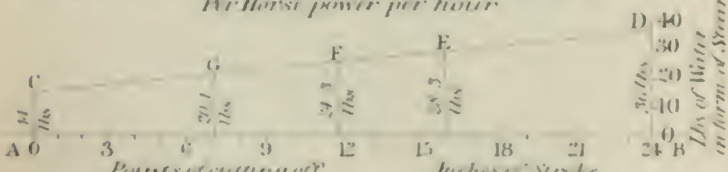
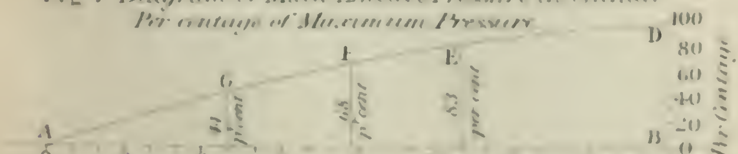


Fig 7 *Diagram of Mean Effective Pressure in Cylinder Per centage of Maximum Pressure*



EXPANSION OF STEAM.

Indicator Diagrams from Locomotives at very slow motion

Fig 2 *Edinburgh & Glasgow Engine Orion*

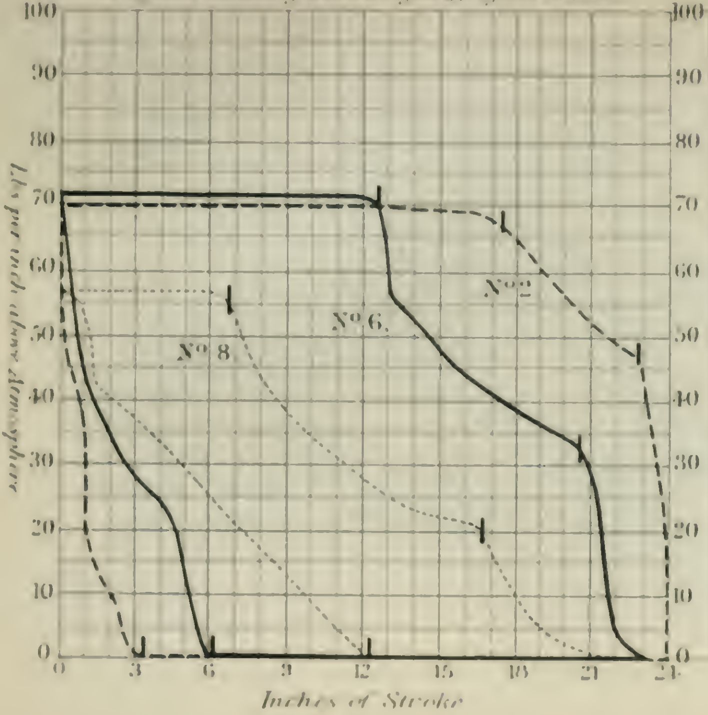
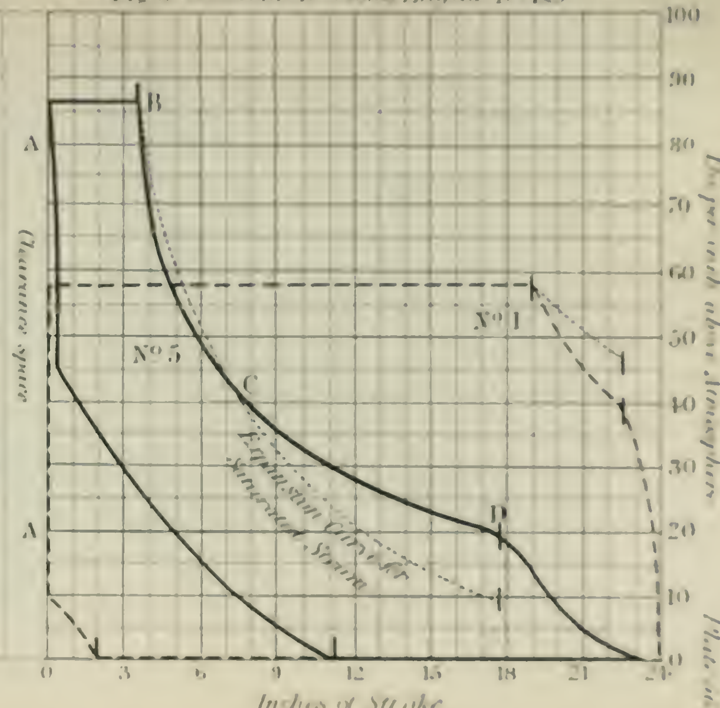


Fig 3 *Caledonian Goods Engine Nº 125*



EXPANSION OF STEAM.

Indicator diagrams from Great Britain Locomotive

Fig 4. At 17 Miles per hour

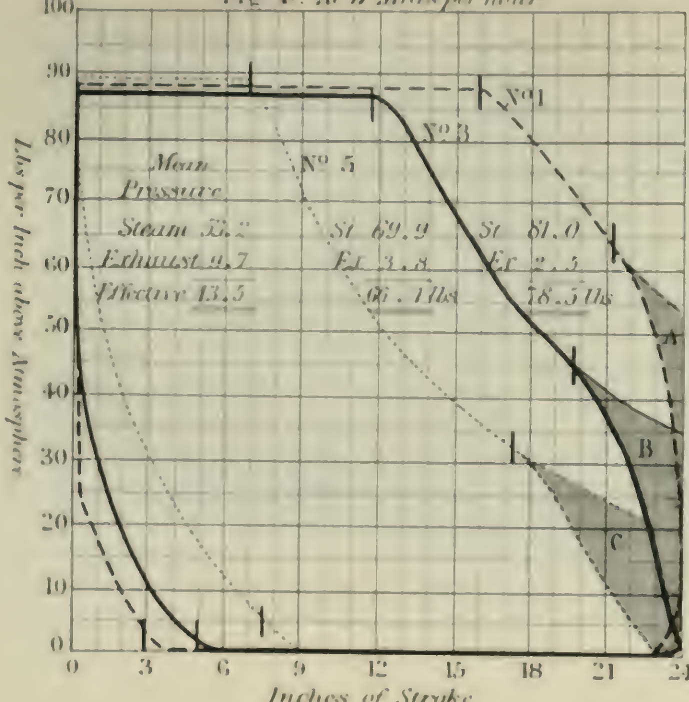


Fig 5. At 55 Miles per hour

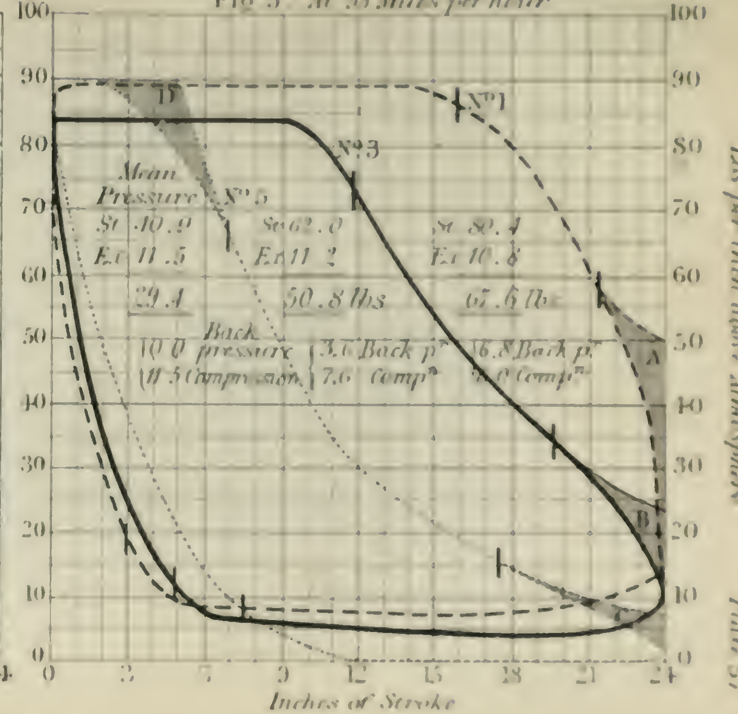


Plate 57

Fig. 1

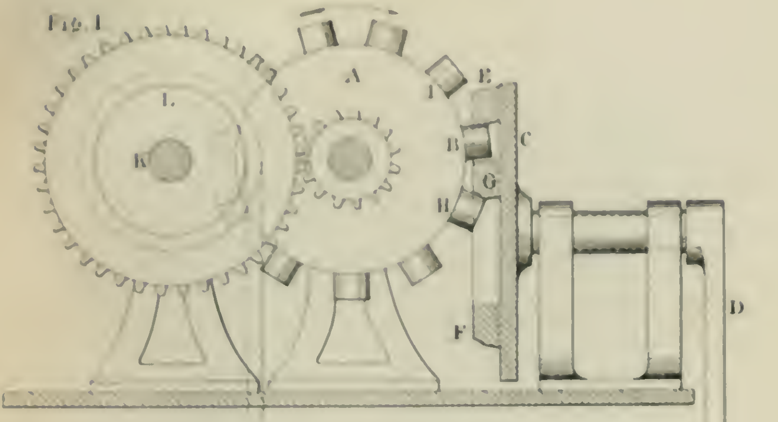
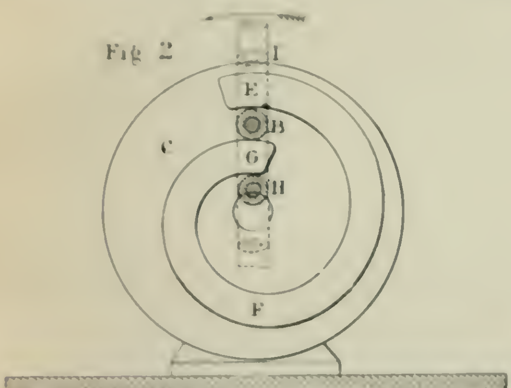


Fig 2



Scale ¼th size

Fig 3 *Rack Pulley*

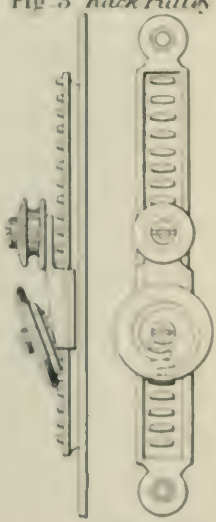


Fig 3 *Parallel Vice*

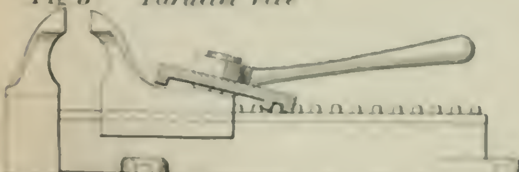
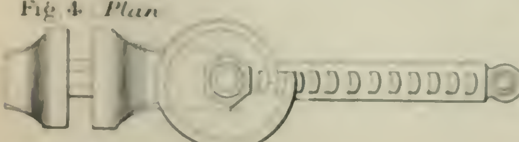


Fig 4 *Plan*



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Scale ½ size

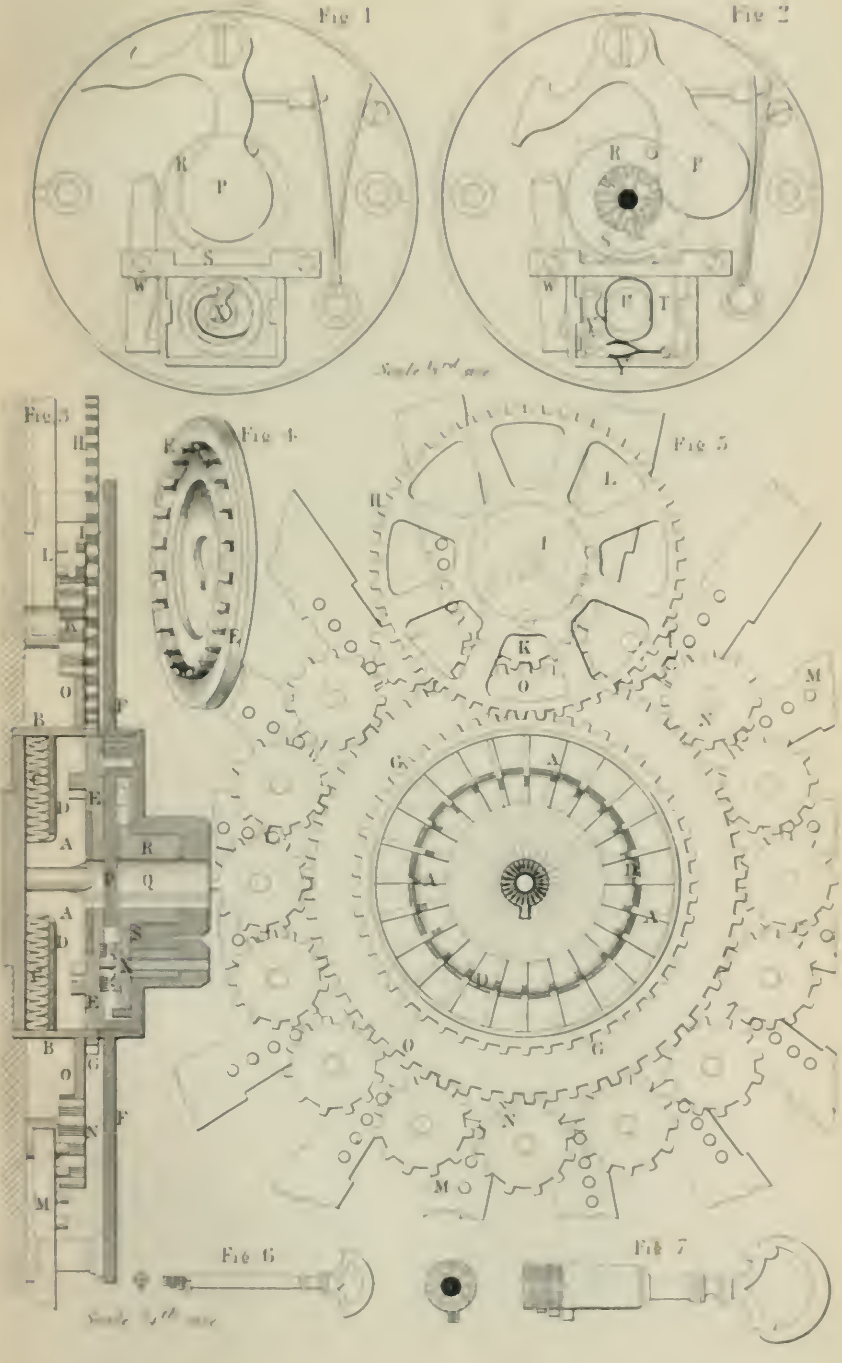
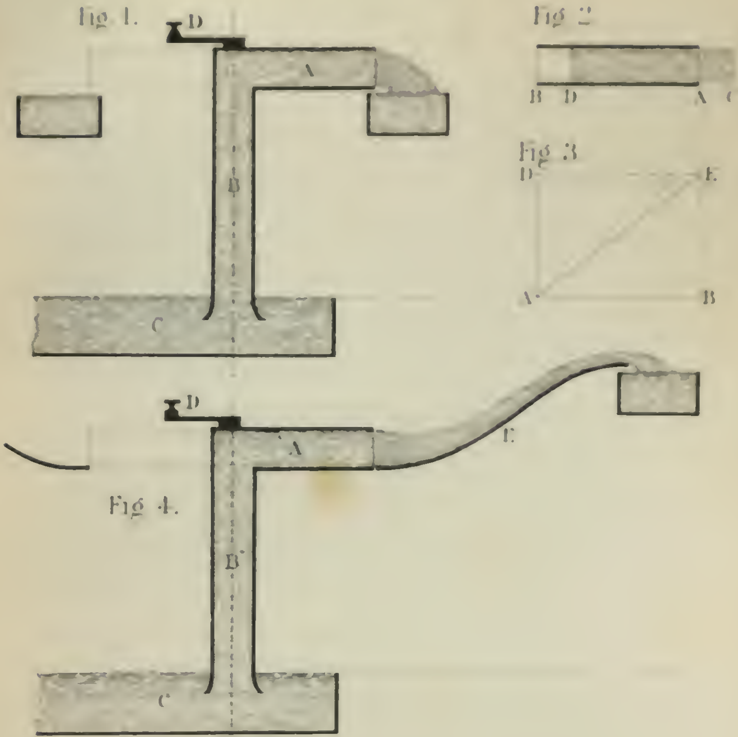


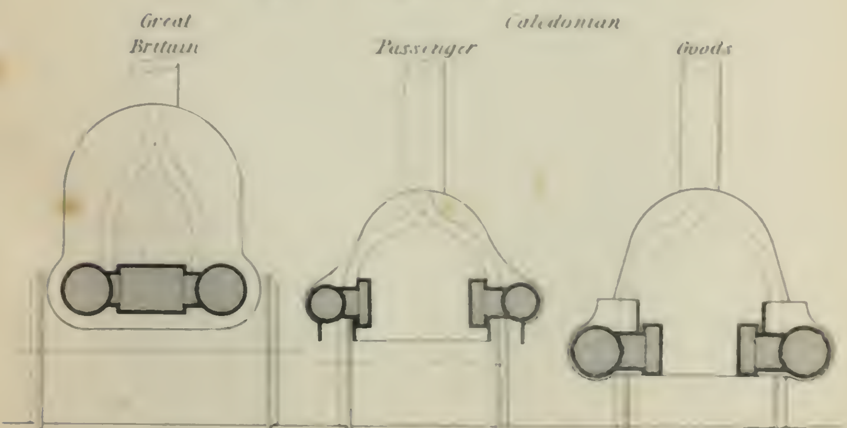
Fig 1
Fig 2
Fig 3
Fig 4
Fig 5
Fig 6
Fig 7

CENTRIFUGAL PUMP.



EXPANSION IN LOCOMOTIVES.

Fig. 5. *Protection of Cylinders*



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EXPANSION IN LOCOMOTIVES.

Fig 1. *Indicator Diagrams at Slow Speed from Caledonian Engine No. 15*

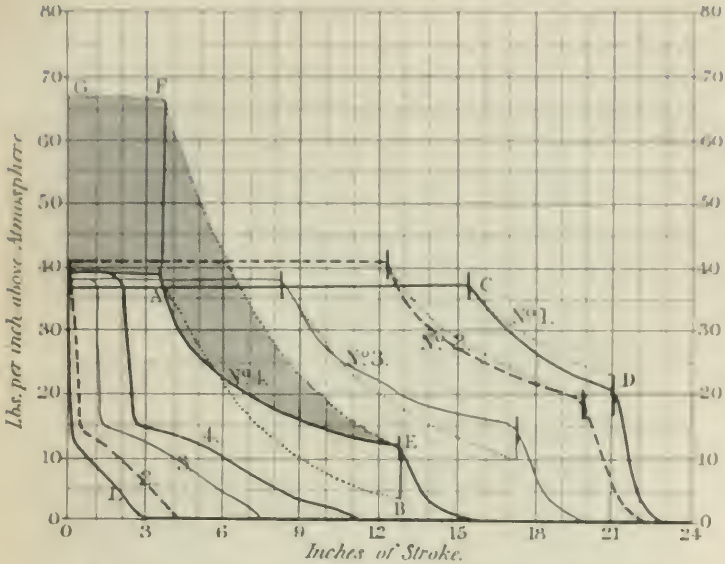
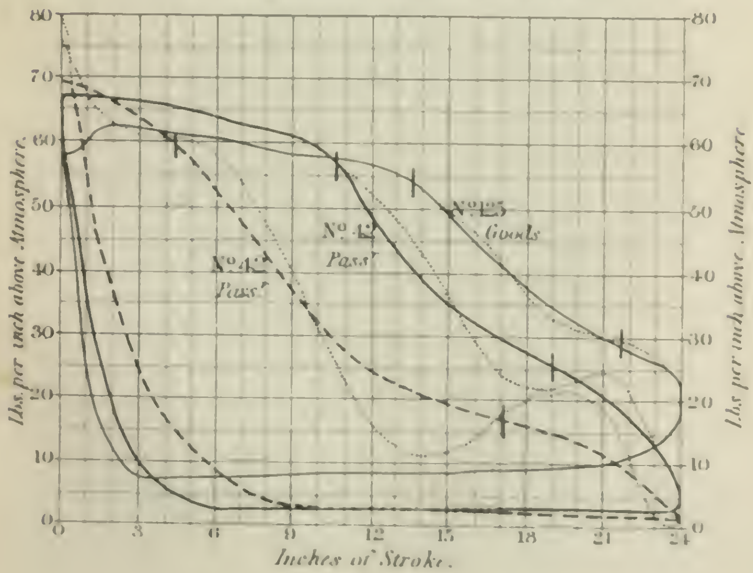
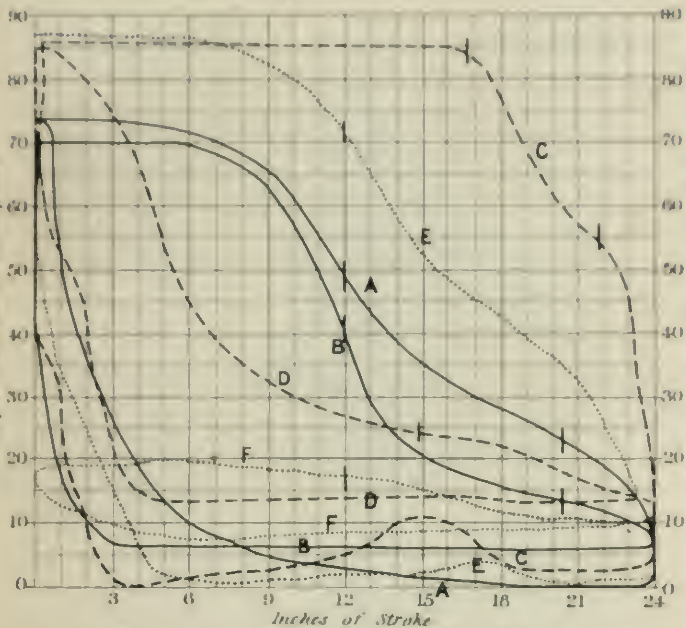


Fig. 2. *Indicator Diagrams at Quick Speed from Caledonian Engines Nos. 42 & 125*



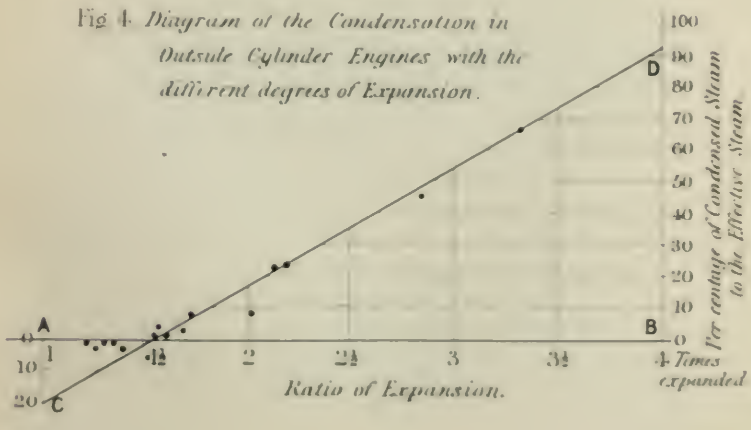
EXPANSION IN LOCOMOTIVES.

Fig 3. *Indicator Diagrams from Locomotives showing increase of Back Pressure caused by Water in the Cylinder*



A & B *Orion Pass.r Engine, 39 Miles per hour*
C & D *No 127 Goods Engine, 18 " "*
E & F *Do Do 15 " "*

Fig 4. *Diagram of the Condensation in Outside Cylinder Engines with the different degrees of Expansion.*



EXPANSION OF STEAM.

Fig 1

Apparatus for Measuring the Total Heat of Steam

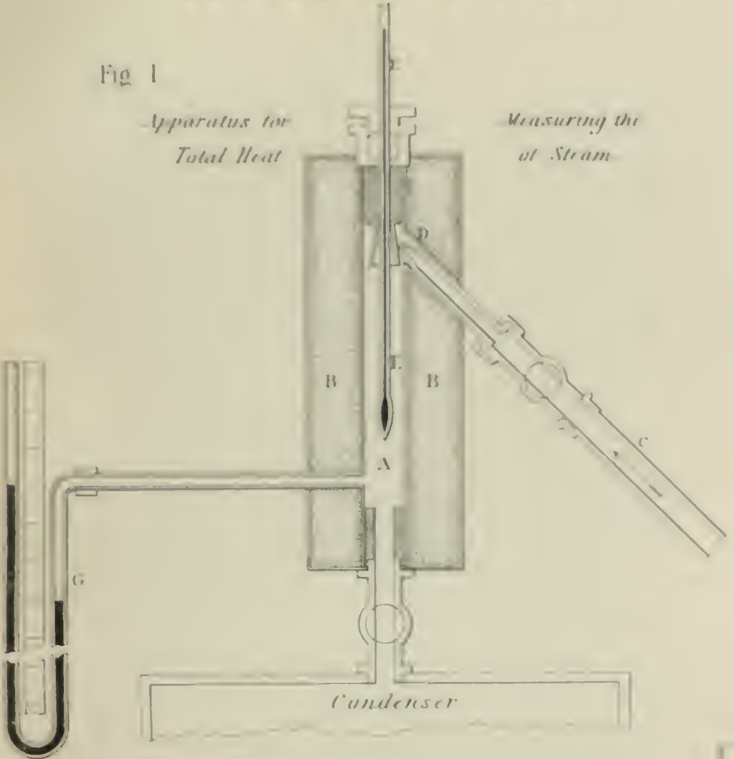
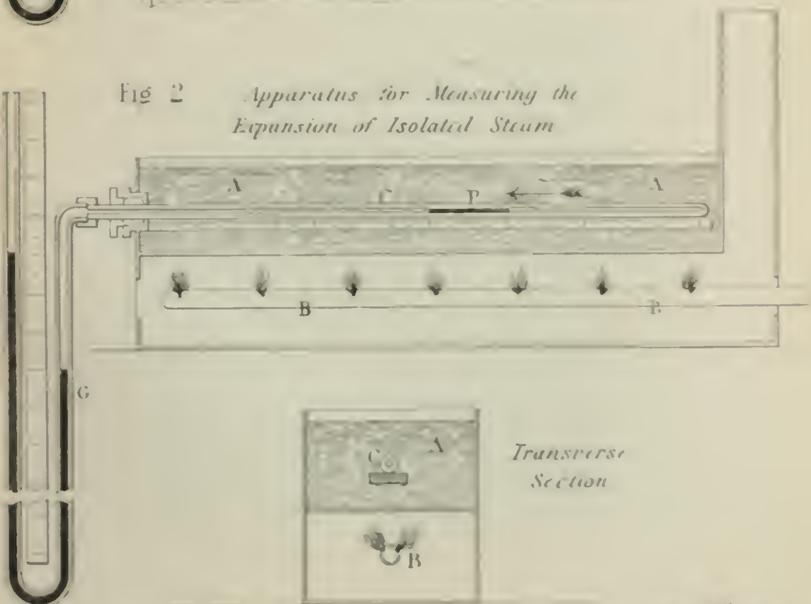


Fig 2 *Apparatus for Measuring the Expansion of Isolated Steam*

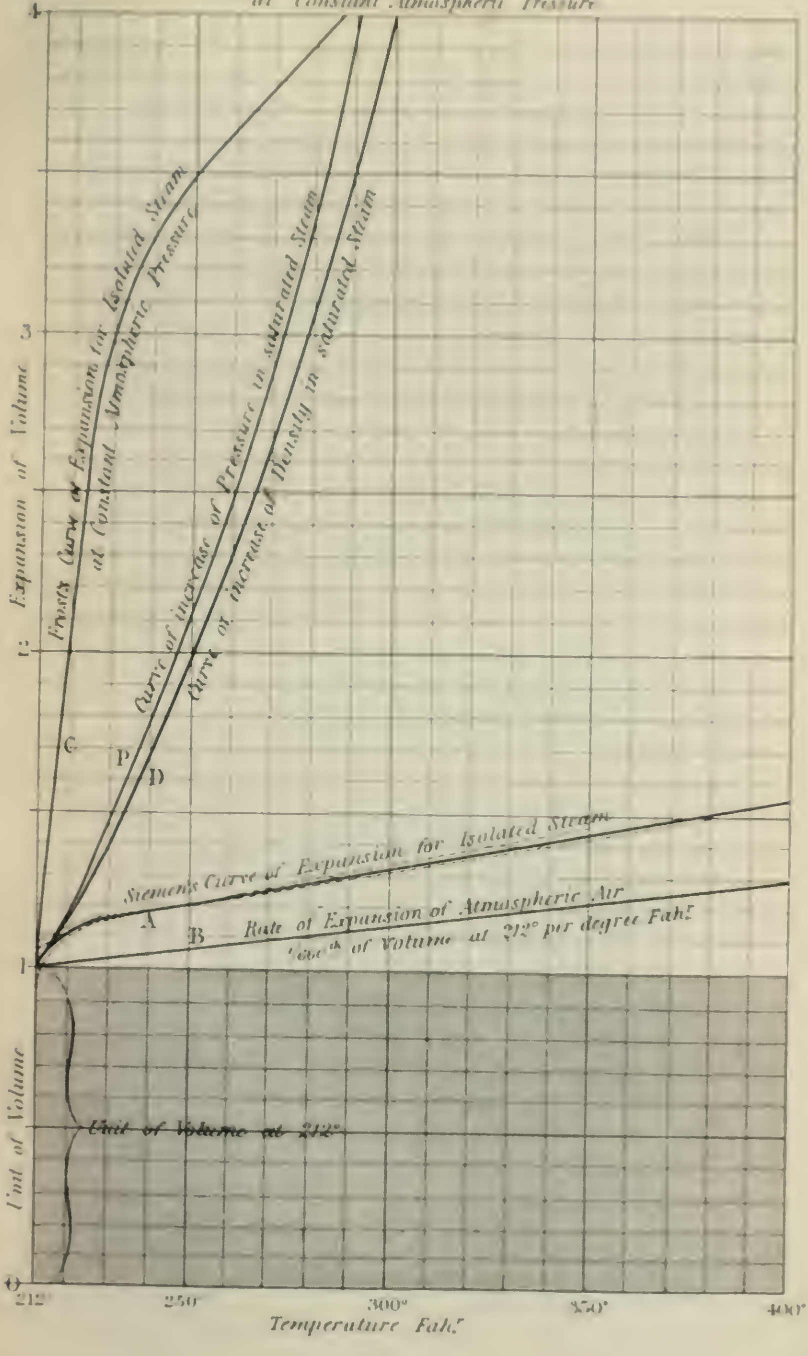


Transverse Section

Scale 1/4th size

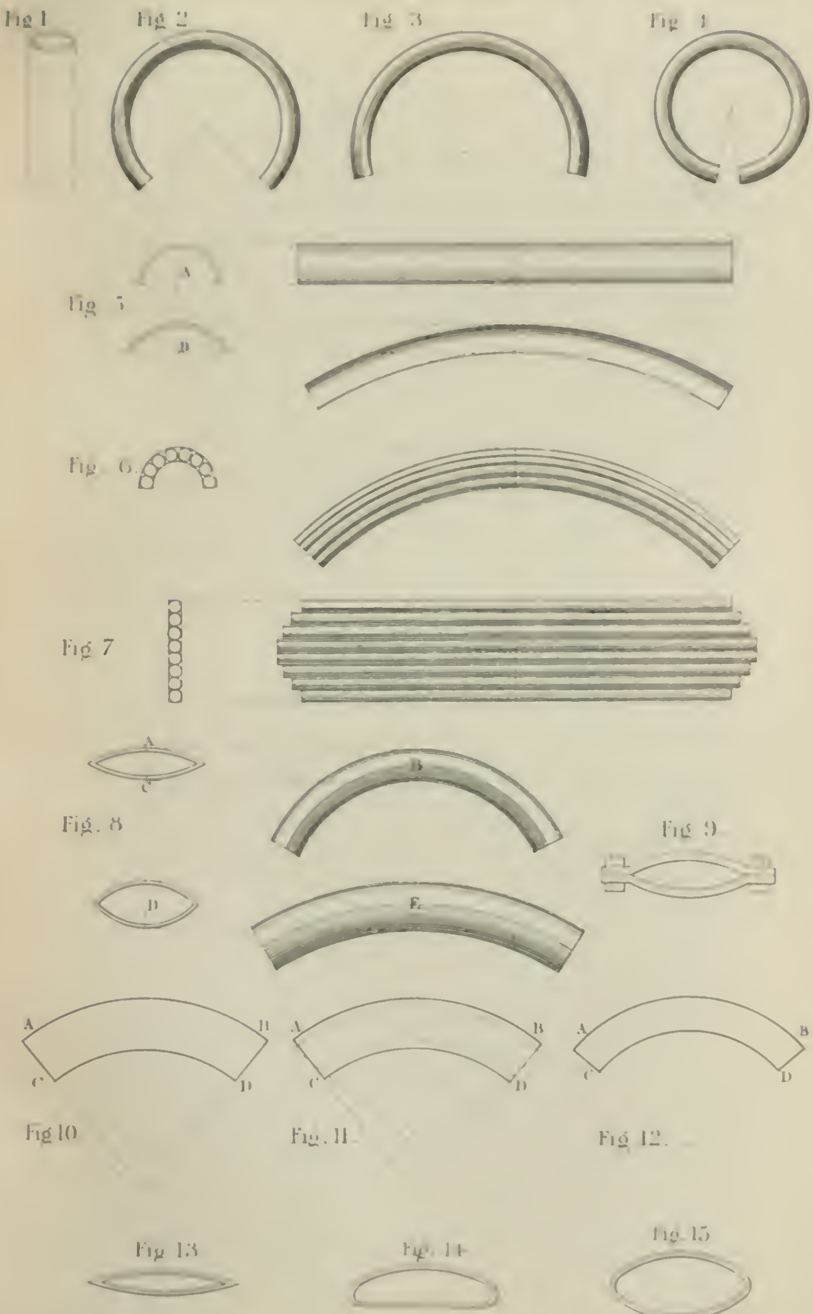
EXPANSION OF STEAM.

Expansion of Isolated Steam by Heat at Constant Atmospheric Pressure



BOURDON'S GAUGES.

Diagrams illustrating the principle of Action



BOURDON'S GAUGES.

Steam Pressure Gauge

Fig. 16

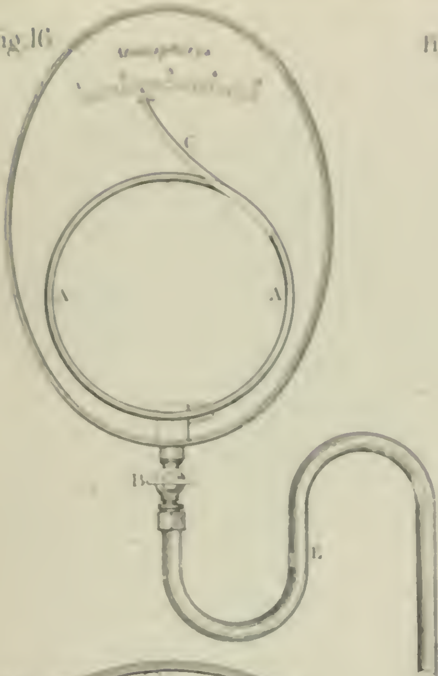


Fig. 17

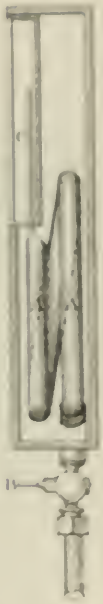


Fig. 18

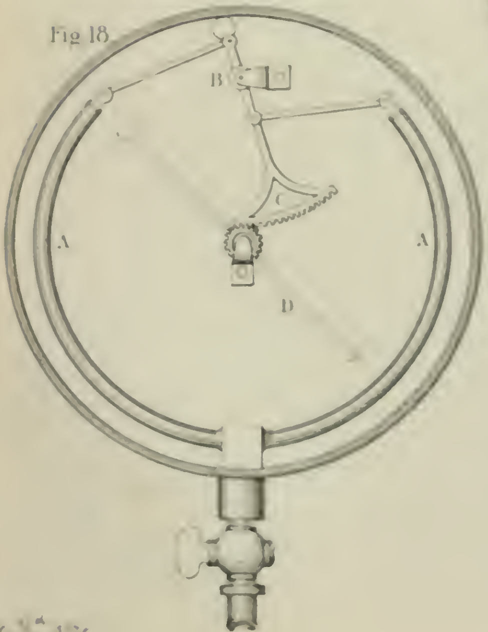


Fig. 19

BOURDON'S GAUGES

Fig 20

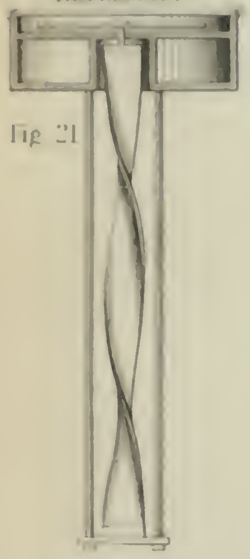


Fig 21

Fig 23

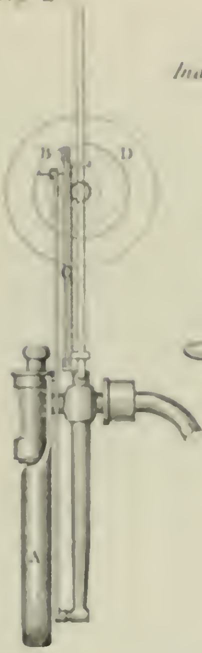
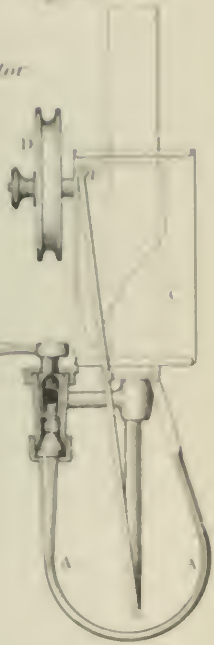
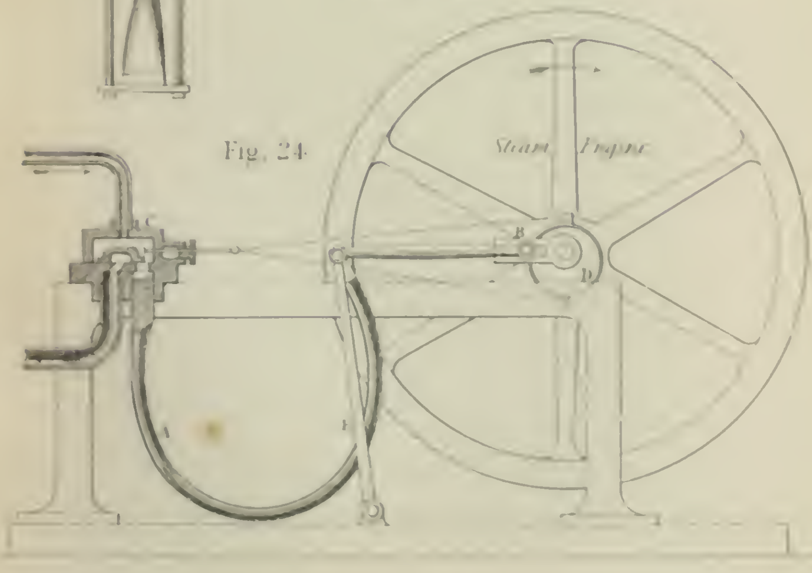


Fig 22

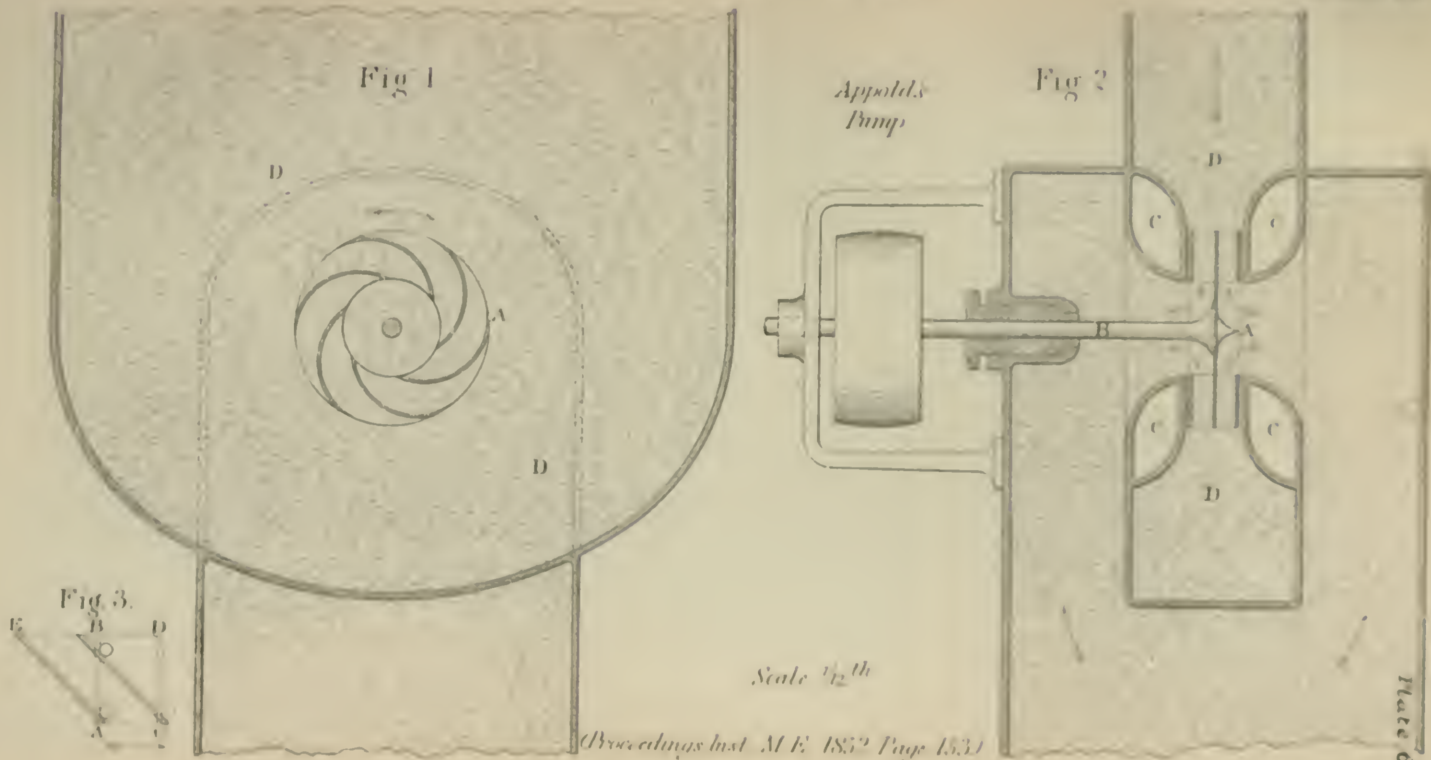


Scale ¼th size

Fig. 24



CENTRIFUGAL PUMP



CENTRIFUGAL PUMP

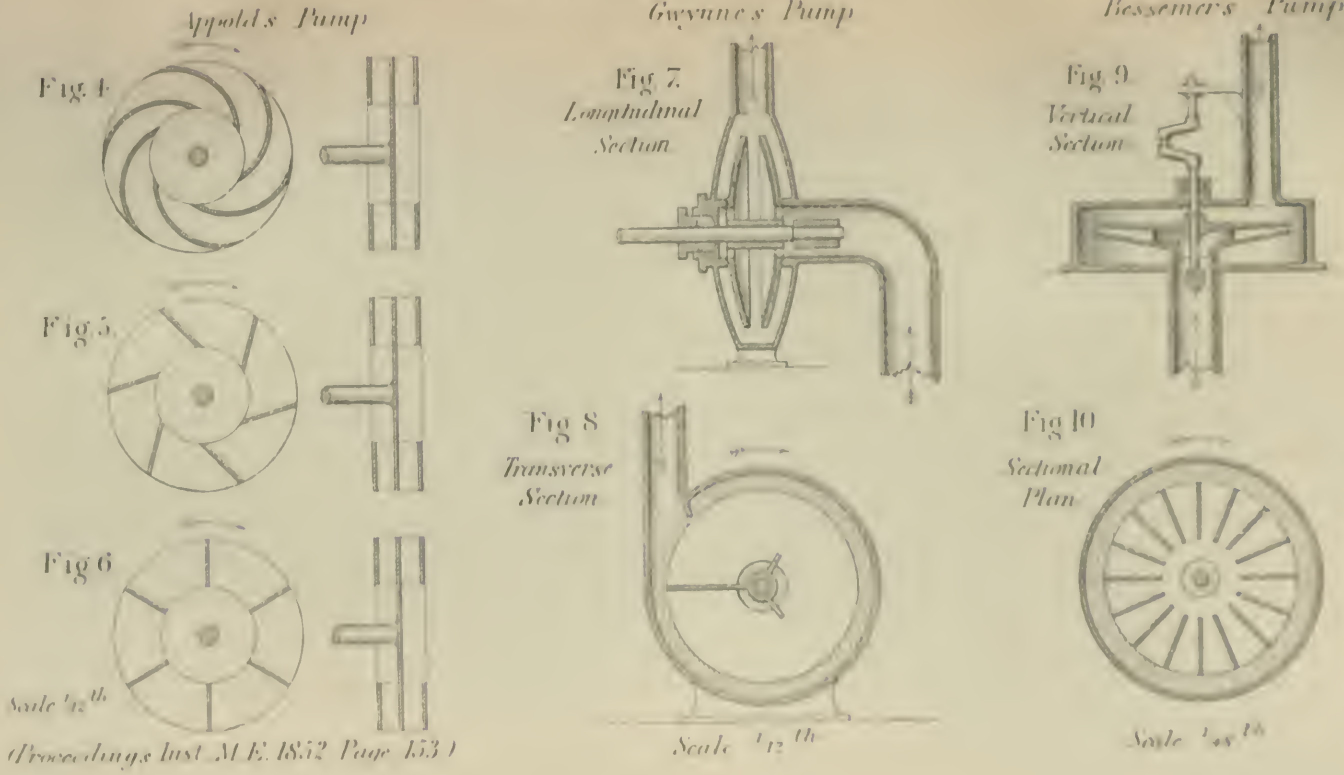


Plate 69.

ORDINARY SCREW PROPELLER

Fig 1.
End View

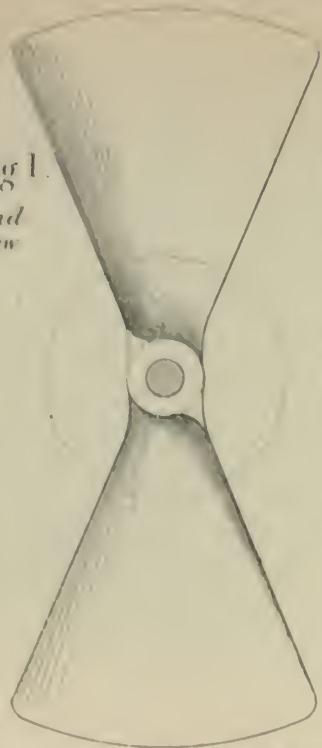


Fig 2.
Side View.

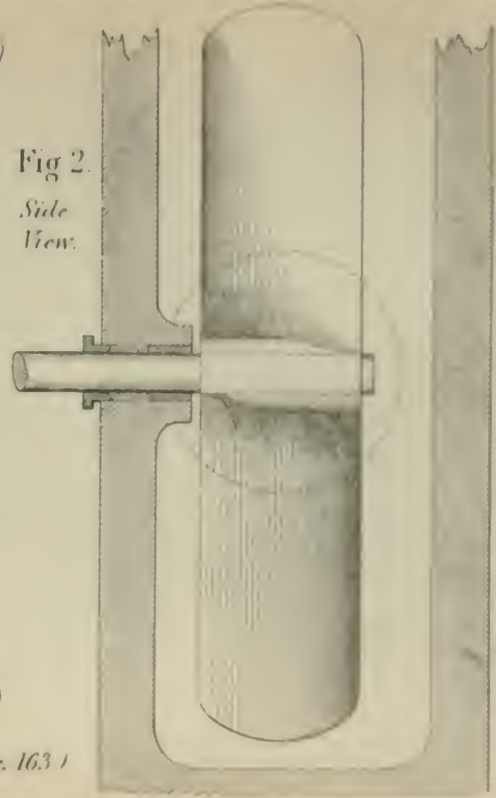
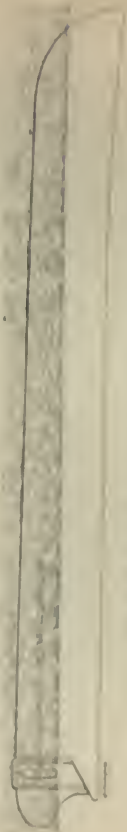


Fig 3
Plan

Scale 1/20th

Fig 4 *The Weaver Screw Steam Boat*



Scale 1/90 th

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IMPROVED SCREW PROPELLER

Fig 5.
End View

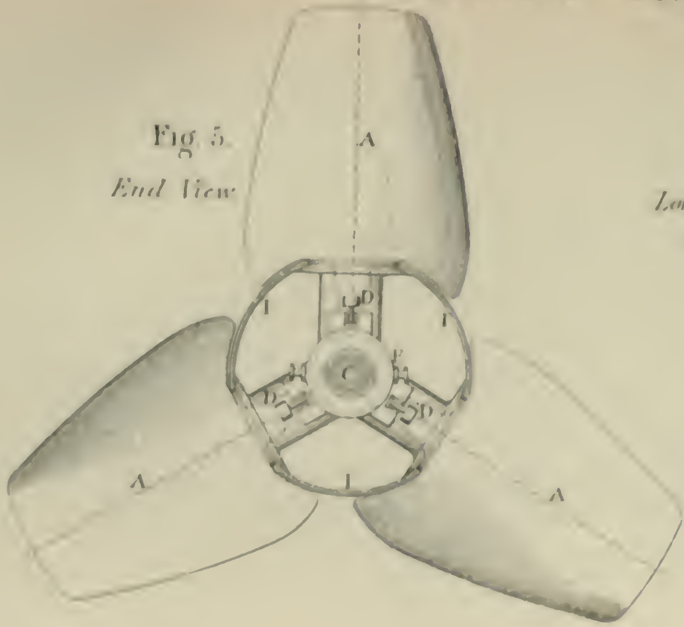


Fig 6
Longitudinal Section

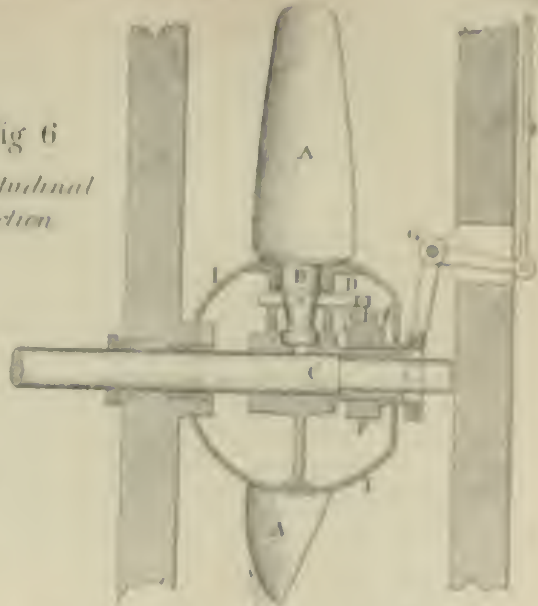
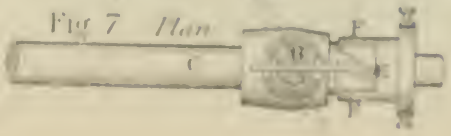


Fig 7 *Plan*



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Scale [illegible]

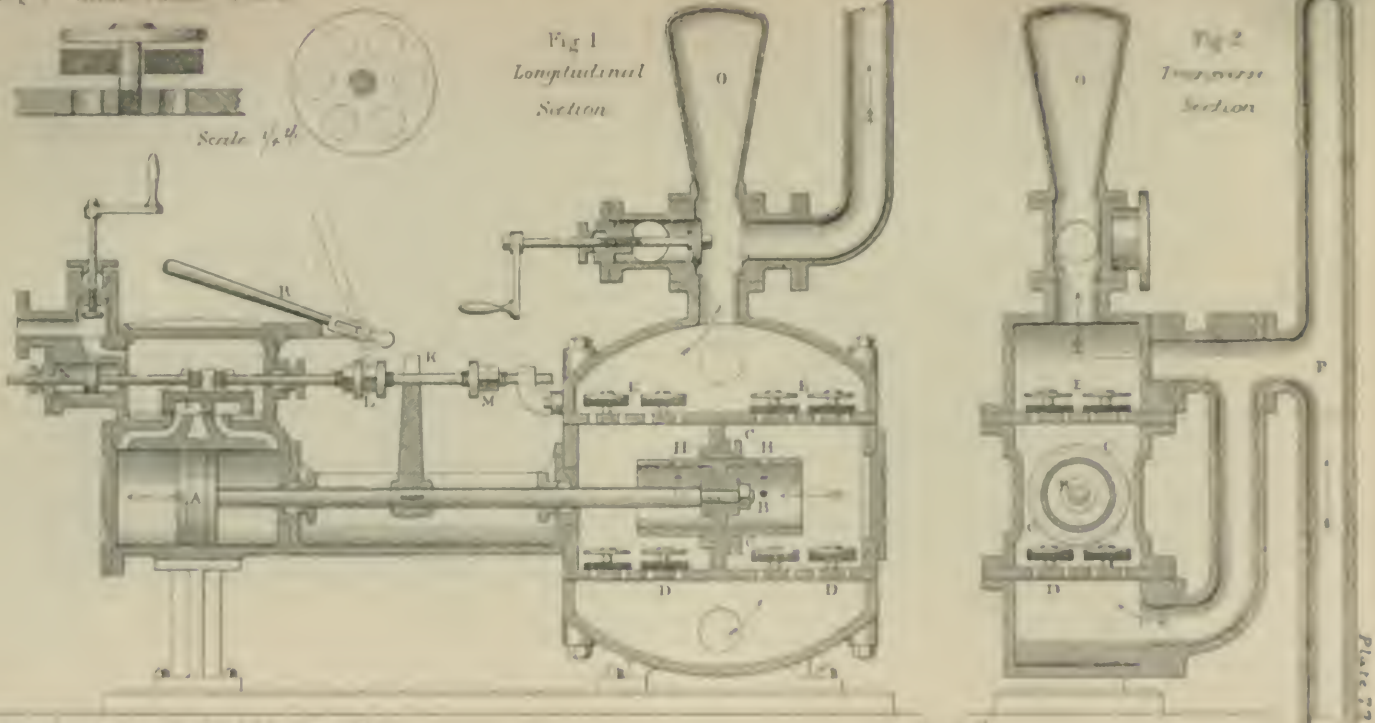
DIRECT-ACTING STEAM PUMP

Fig 3 India rubber Valves

Scale ¼

Fig 1 Longitudinal Section

Fig 2 Transverse Section



Scale

FIRE-BRICK GAS RETORTS

Fig 1 Front Elevation

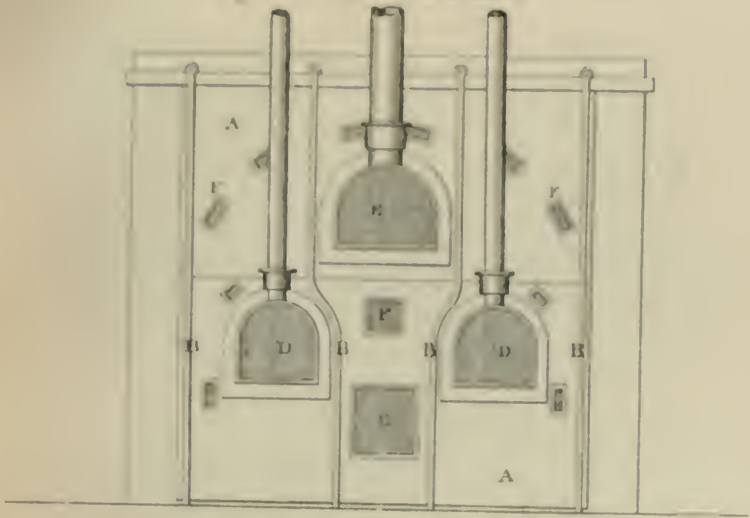


Fig 3 Details of Arch Bricks Scale [illegible]

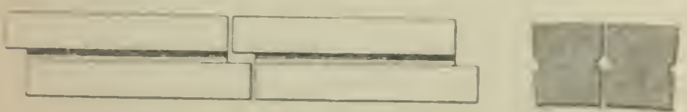
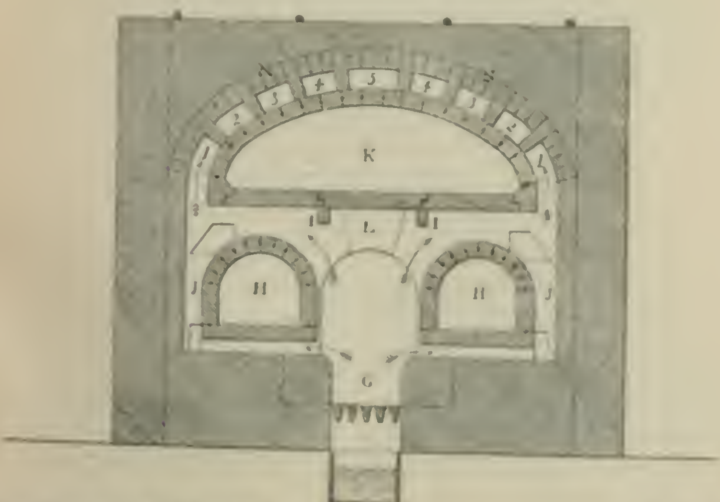


Fig 2 Transverse Section



Scale [illegible]

FIRE-BRICK GAS RETORTS

Fig. 4 Longitudinal Section

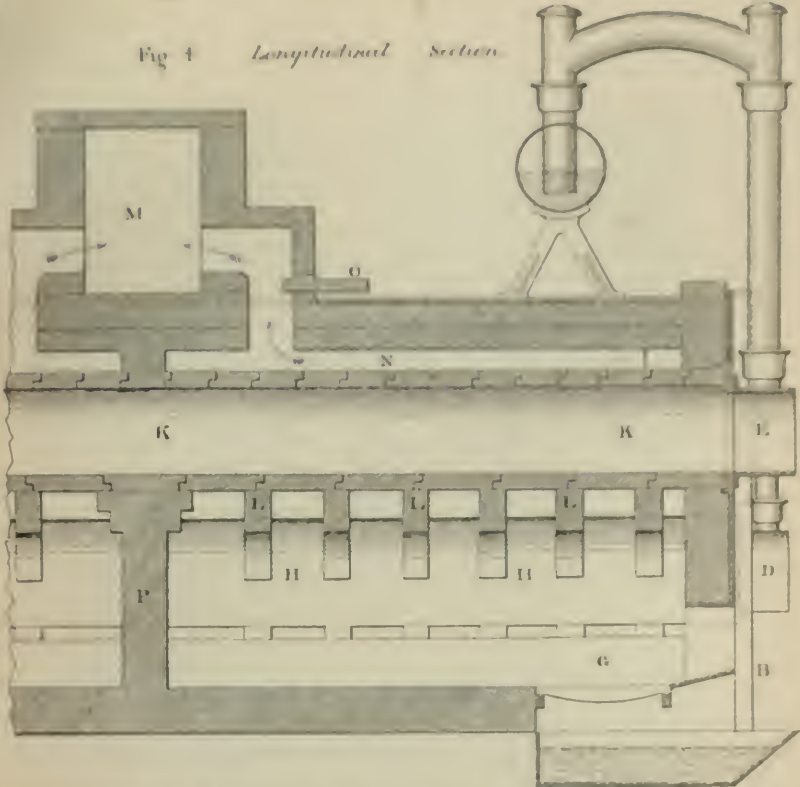
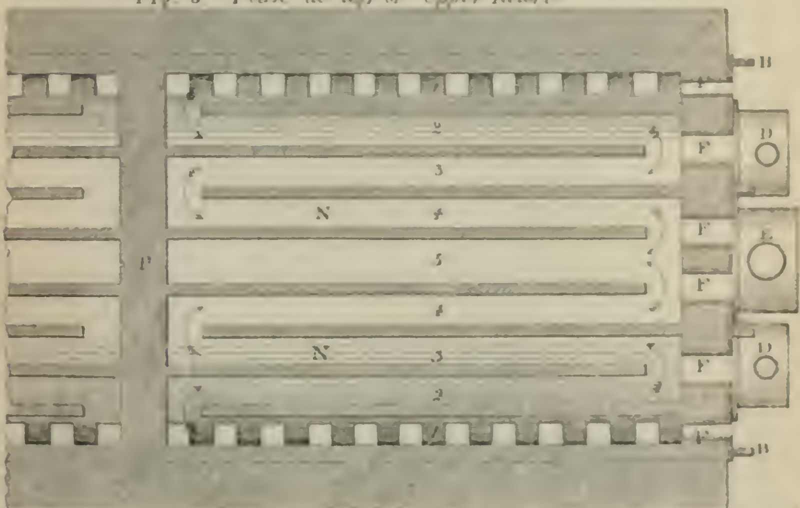


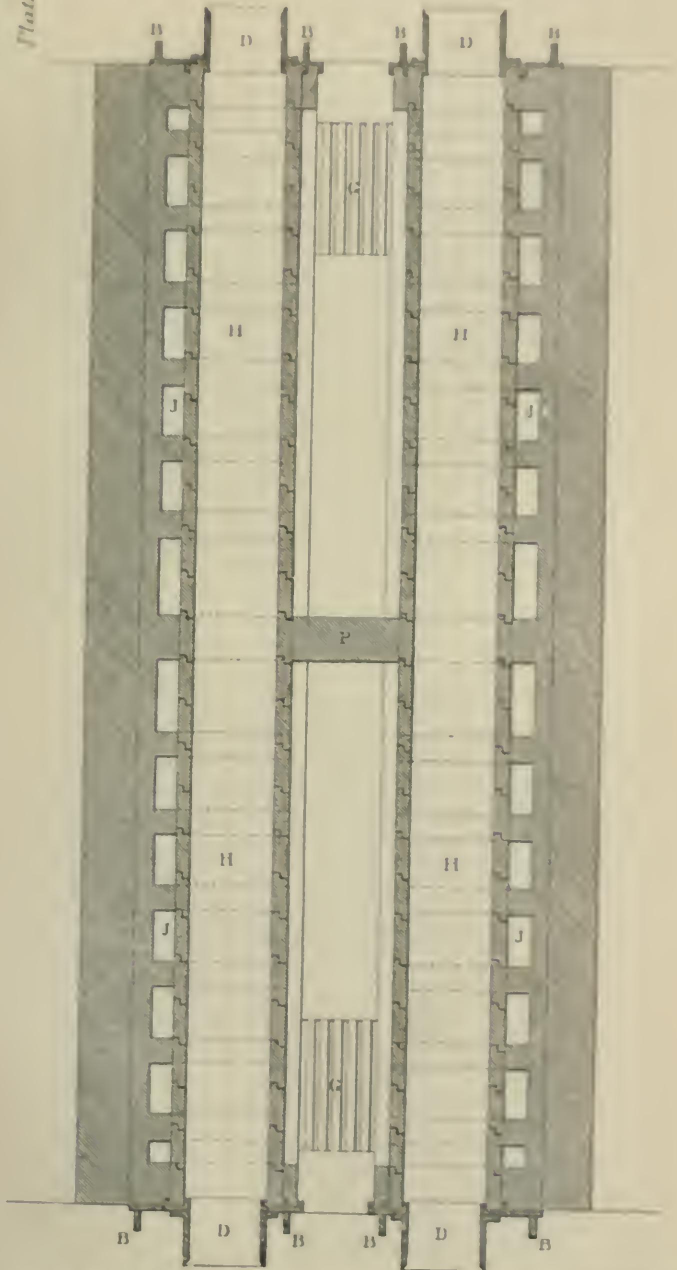
Fig. 5 Plan at top of Upper Retort



Scale

FIRE-BRICK GAS RETORTS *Plate 75*

Fig 6. Plan at centre of Lower Retorts



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Scale 1/40th

BLAST FURNACES *Plate 76.*

Arrangements for Taking Off the Waste Gases.

Fig. 1. *Ystalyfera, South Wales.*

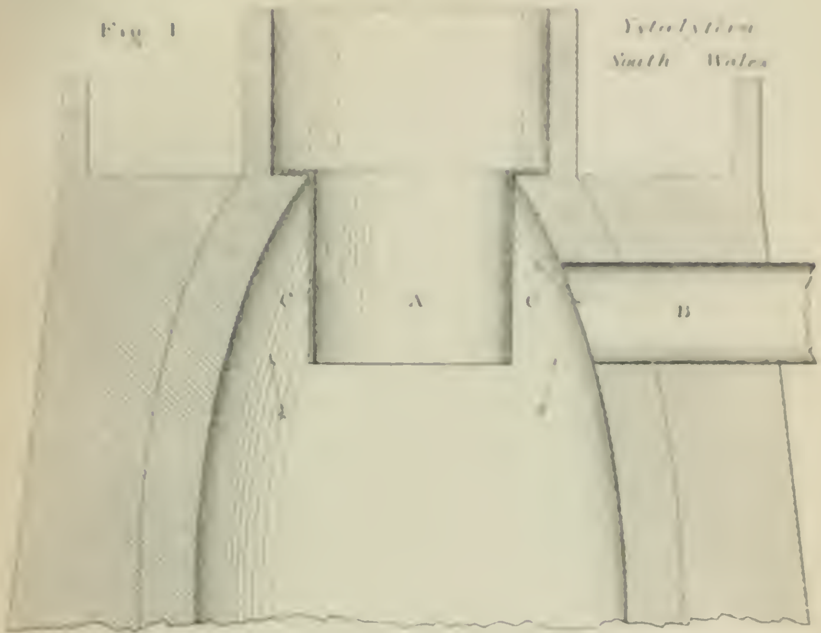
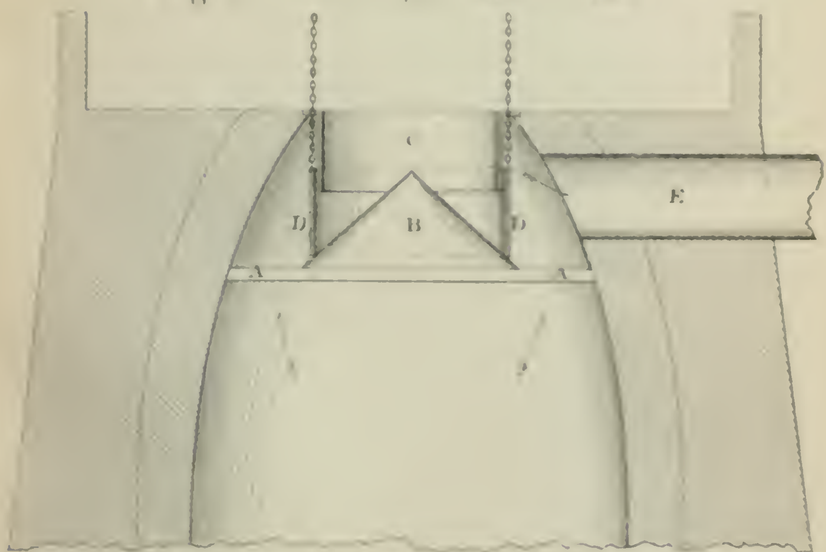


Fig. 2. *Cwm Celyn, South Wales.*



Proceedings Inst. M. E. 1852. Page 191. *Scale*

0 5 10 15 20 25 30 Feet

Arrangements for Taking Off the Waste Gases

Fig. 3. *Ebbw Vale South Wales*

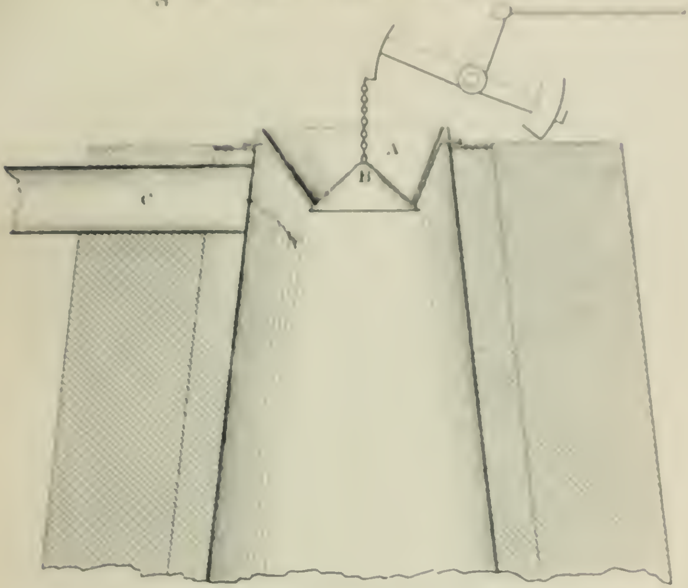
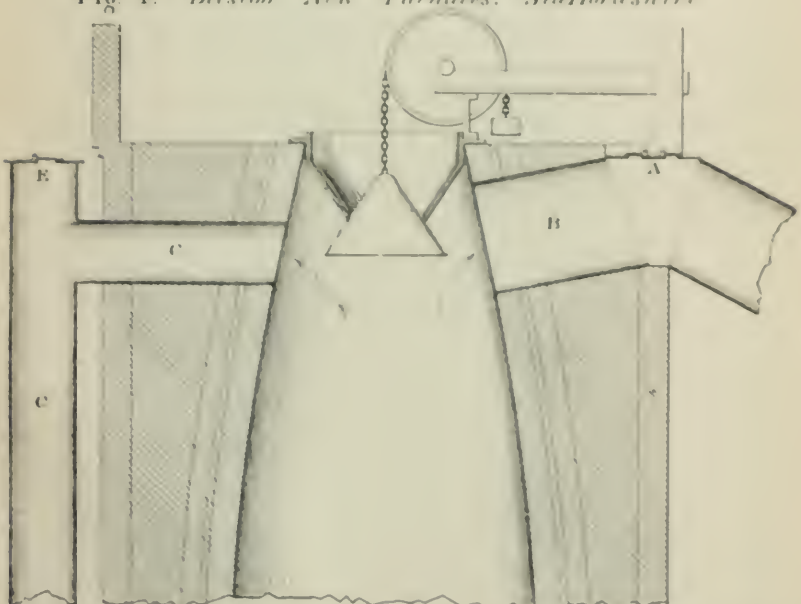


Fig. 4. *Bilston New Furnaces. Staffordshire*



(Proceedings Inst. M.E. 1852 Page 191) *Scale 1/100th*

0 5 10 15 20 25 30 *Feet*

BLAST FURNACES *Plate 78*

Arrangements for Taking Off the Waste Gases

Fig 5 *Dundyvan Scotland*

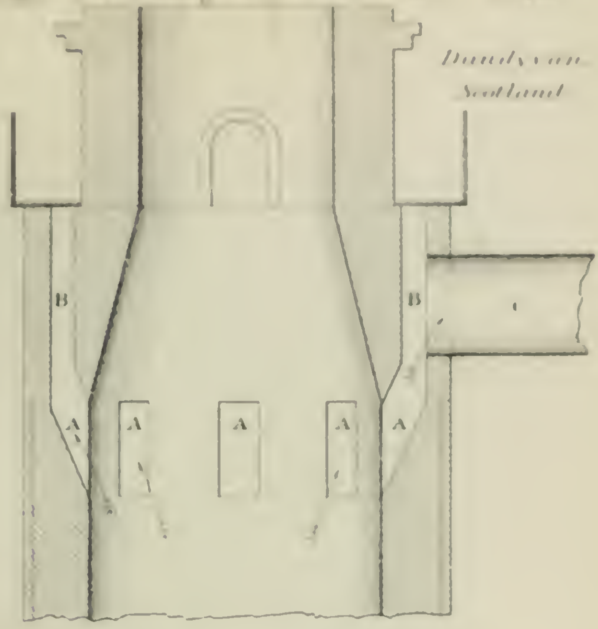
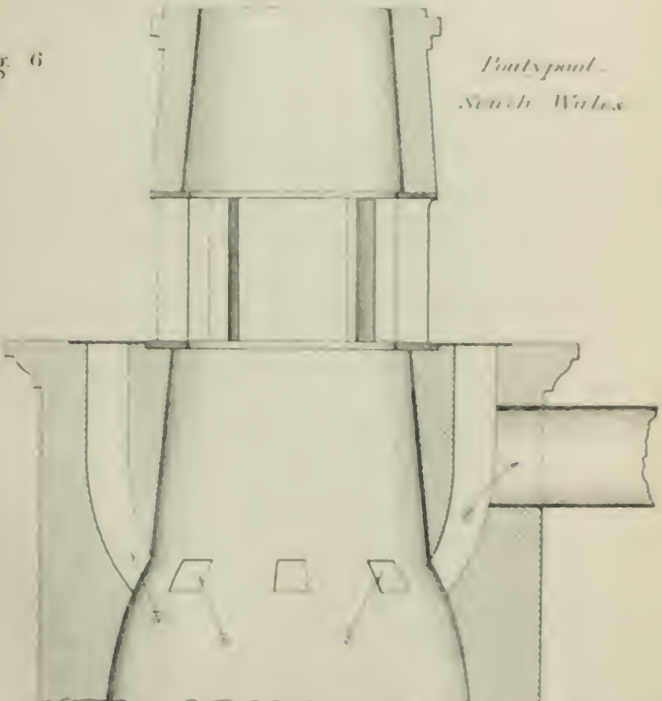


Fig 6 *Pontypool South Wales*

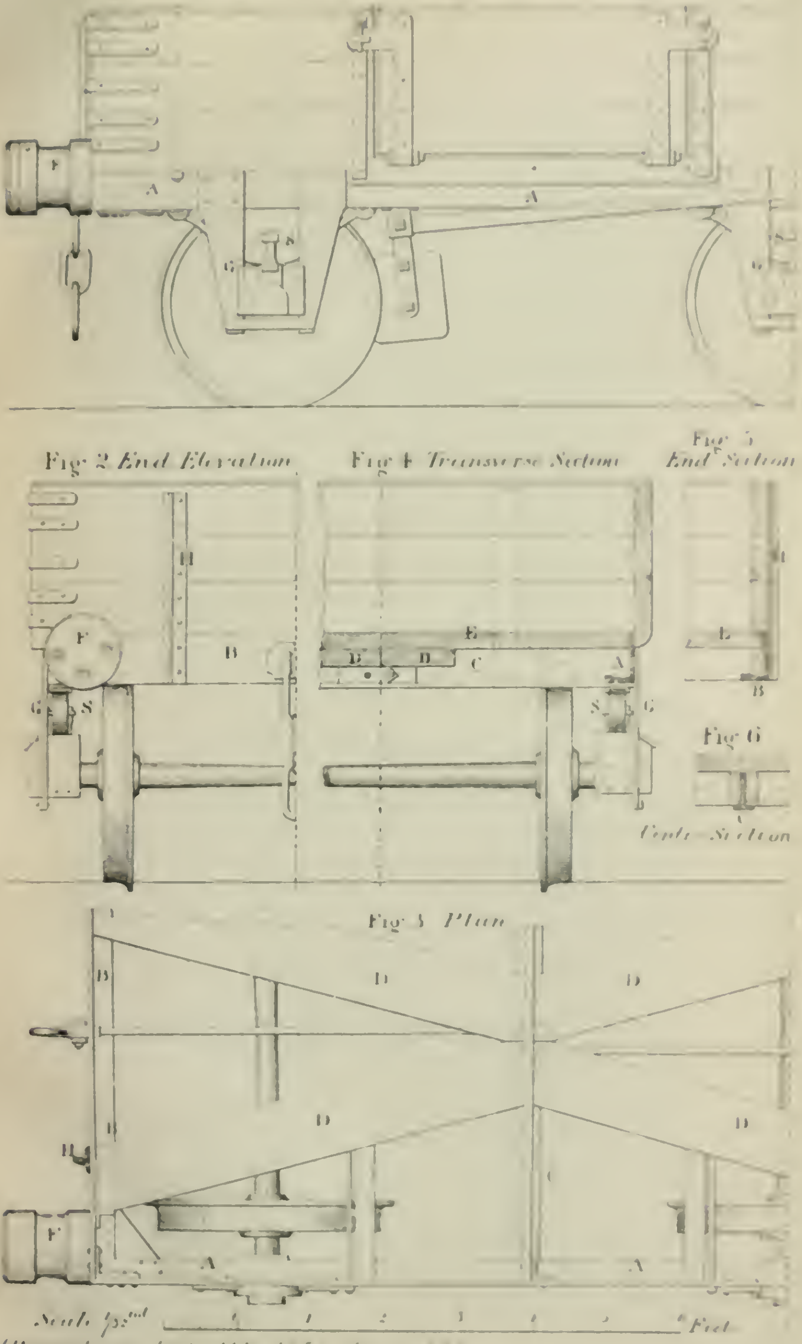


(Proceedings Inst. M.E. 1852 Page 191.) *Scale 1/100th*

0 5 10 15 20 25 30 *Feet*

CONSTRUCTION OF RAILWAY WAGONS *Plate 19*

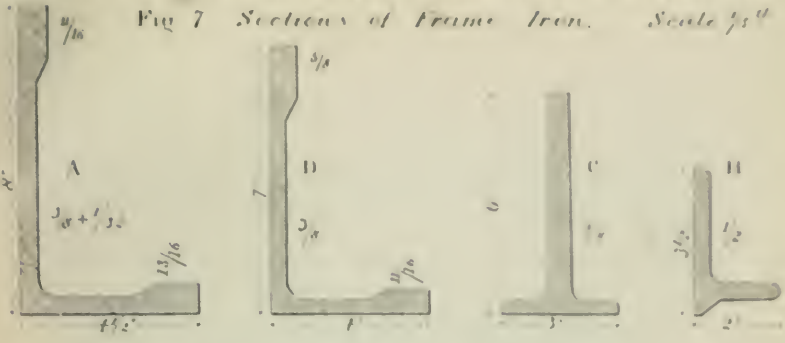
Fig. 1 *Side Elevation of new Iron-Framed Wagon*



(*Proceedings Inst. M.E. 1852 Page 200*)

CONSTRUCTION OF RAILWAY WAGONS *Plate 30*

Fig 7 Sections of Frame Iron. Scale 3/8"



Ordinary Wood Framed Wagon

Fig 8 Side Elevation *Fig 9 Transverse Section*

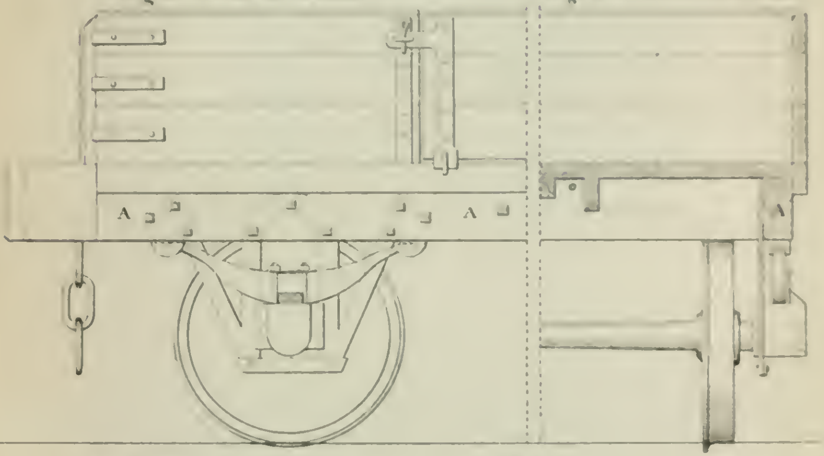
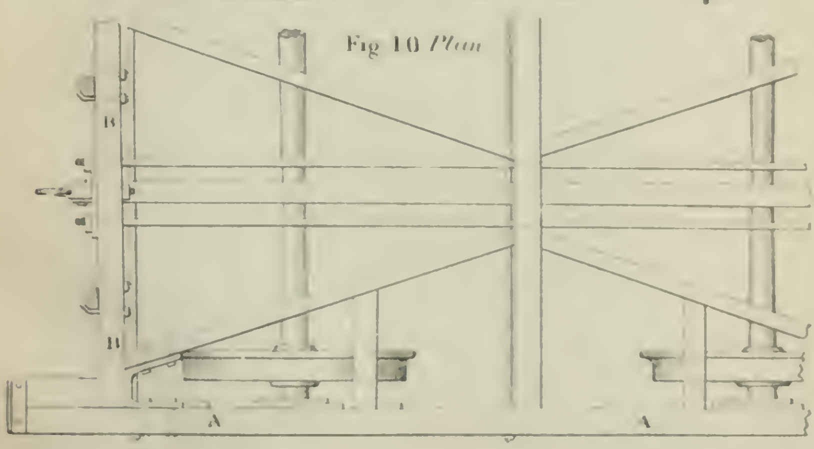


Fig 10 Plan



Scale 1/32nd 0 1 2 3 4 5 6 *Feet*

Fig. 1 *Longitudinal Section*

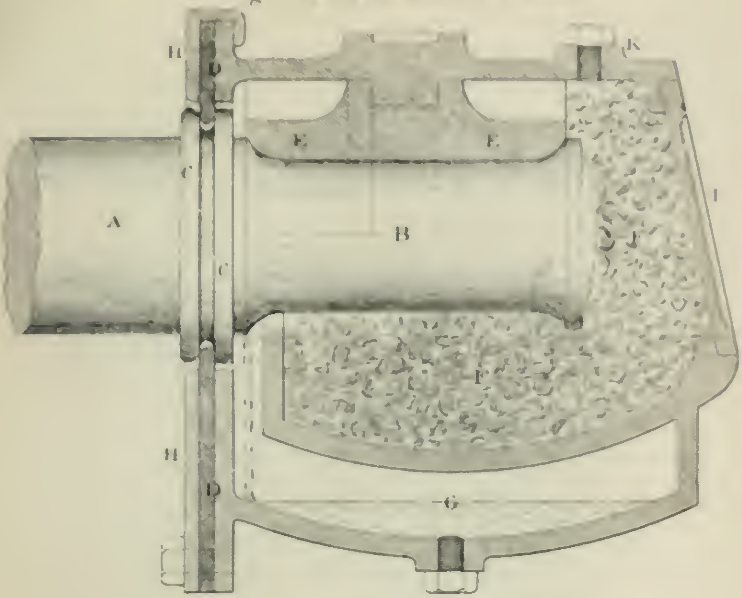


Fig. 2. *Transverse Section*

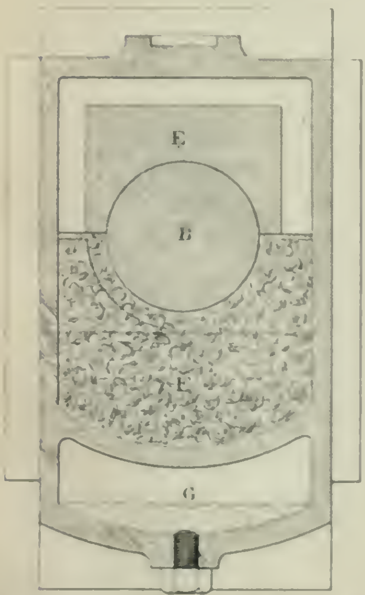
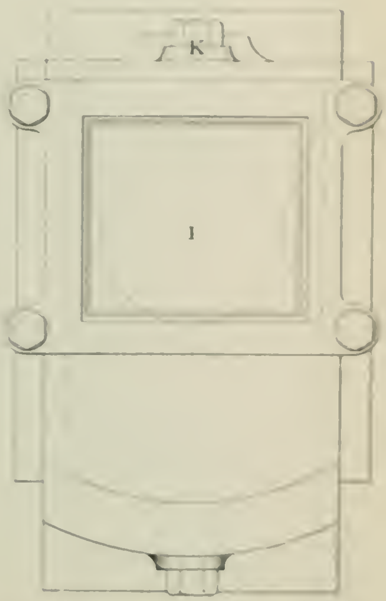


Fig. 3 *Front Elevation*



 Scale ¼th

SELF-LUBRICATING AXLEBOX. *Plate 82.*

Fig 4. Back Elevation

Fig 5. Leather Flange

Scale 1/4th

SELF-ACTING SPRING CROSSING.

Fig 6. *Plan of No 1 Crossing.* *Scale 1/12th*

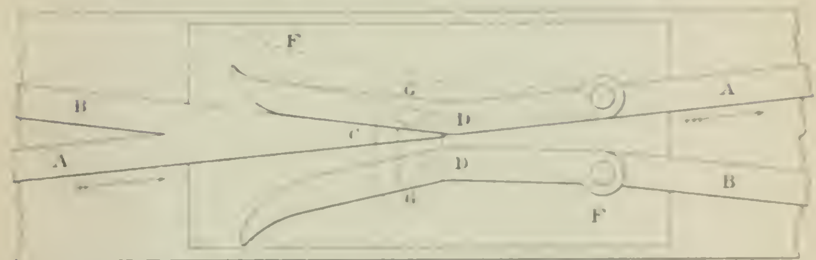
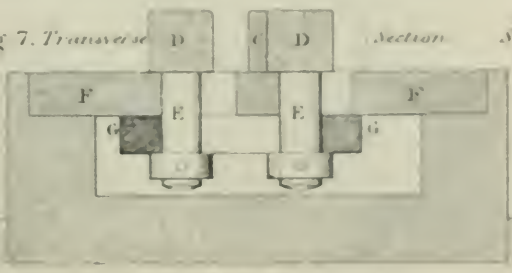


Fig 7. *Transverse Section* *Scale 1/6th*



(Proceedings Inst. M. E. 1852. Page 216.)

Fig. 8. *Plan of No 2 Crossing* *Scale 1/12th*

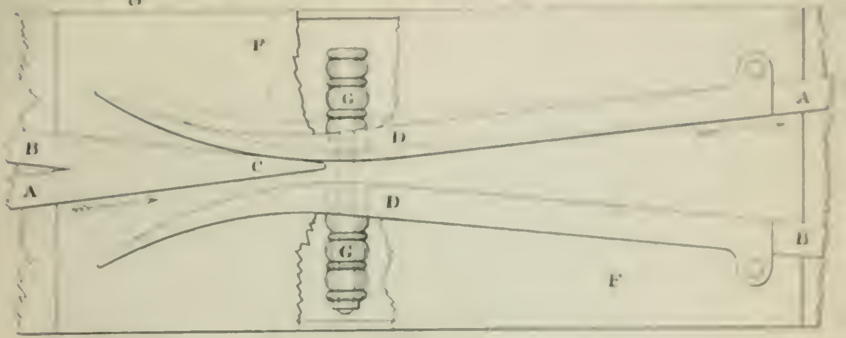


Fig 9. *Transverse Section* *Scale 1/6th*

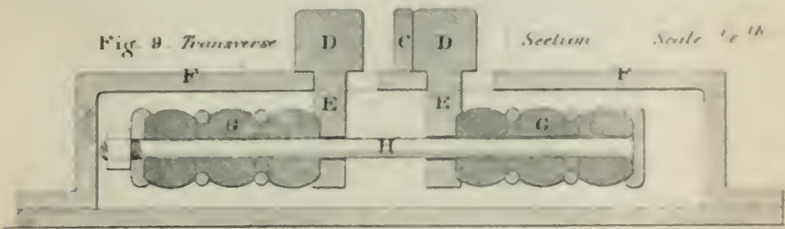


Fig 10. *Plan of Crossing* *Scale 1/24th*

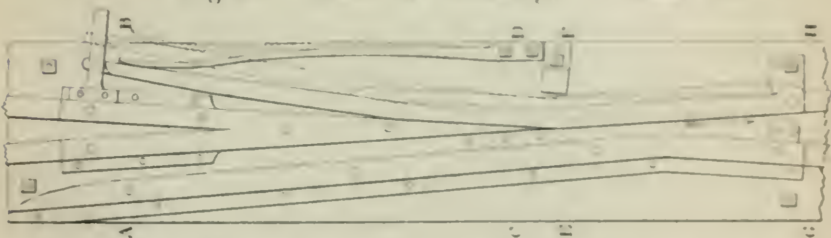


Fig 11. *Section at* A B.

Fig 12. *Section at* C D.

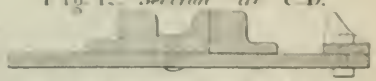


Fig 13. *Section at* E F

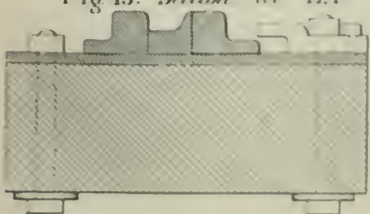
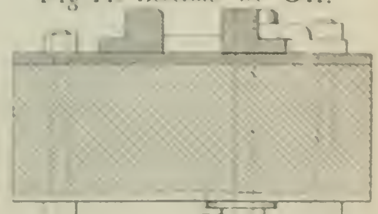


Fig 14. *Section at* G H.



(Proceedings Inst M E 1852 Page 216) *Sections Scale 1/32th*